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Prairie Village, KS

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DATA COLLECTION AND ANALYSES PERTINENT TO EPA'S DEVELOPMENT OF GUIDELINES FOR PROCUREMENT OF HIGHWAY CONSTRUCTION PRODUCTS CONTAINING RECOVERED MATERIALS

Volume I

Issues and Technical Summary

This report (ms. 2096) describes work performed
for the Office of Solid Waste under contract no. 68-01-6014
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U.S. ENVIRONMENTAL PROTECTION AGENCY
1981

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Publication does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of commercial products constitute endorsement by the U.S. Government.

PREFACE

This report was prepared as a joint venture with Franklin Associates, Ltd. of Prairie Village, Kansas, and Valley Forge Laboratories, Inc., of Devon, Pennsylvania. Franklin Associates was prime contractor on the project. The study was performed for the U.S. Environmental Protection Agency, Office of Solid Waste, under Contract No. 68-01-6014.

This report has been separated into two volumes because of its size. Volume One is the "Issues and Technical Survey." Volume Two is "Technical Data and Appendices," which contains the full technical reports authored by Valley Forge Laboratories, as well as appendices which contain support documentation for the entire report.

This project relied heavily on interviewing people knowledgeable about the procurement process, and about the issues relevant to this project. We are indebted to the numerous people who contributed to this project. They include people in state, local, and Federal government service, suppliers of highway construction material, contractors, trade associations, and others. Special recognition is made to the American Association of State Highway Transportation Officials (AASHTO) who put forth substantial effort to secure information for this project.

Finally, appreciation is due William J. Kline who served as the EPA project officer, and to John M. Heffelfinger and Penelope Hansen who provided general guidance for the study.

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Chapter 1

INTRODUCTION

BACKGROUND

In the eleven years since the passage of the Resource Recovery Act of 1970, EPA has devoted much of its resources to the area of making recovered materials more readily available from waste streams. A wide range of possibilities have been explored, which include voluntary source separation programs to resource recovery from solid waste by technologically sophisticated plants. Much emphasis has been on the "supply-push" concept which assumes that abundantly available raw materials derived from waste will be more economical for industrial users than virgin materials.

In the more recently passed Resource Conservation and Recovery Act of 1976, as amended, however, there is a mandate from Congress for EPA to explore the possibility of the "demand-pull" side of recovered materials markets. The concept is that Federal procurement can provide leadership in creating a market for products utilizing materials recovered from waste streams.

In order to carry out this mandate, EPA has matched components of solid waste with products that the Federal Government purchases. EPA has been mandated to provide a mechanism through which the government can create demand for the materials recovered from waste streams through the product procurement process.

The plan to do this will proceed in stages. First, a data base must be assembled on the recovered material-product matchups to determine how appropriate procurements can proceed within the confines of the four "reasonables"—competition, cost, availability, and technical performance. The data base will then be used to write guidelines for the procurement processes. EPA will then assist procuring agencies at all levels of government in implementing the guidelines.

OBJECTIVE OF THIS STUDY

The primary objective of this study is to prepare a base of quantitative and qualitative information relating to the writing of guidelines for government procurement of four categories of recovered materials which are suitable for use in highway construction products: power plant ash, cement and lime kiln dusts, rubber tires, and incinerator residue. Specifically, the following kinds of information are to be provided to EPA:

1. Commercial availability of products containing recovered materials.

2. Indirect capacity to produce and supply those products.
3. Procuring agency demand.
4. Price ranges for products containing recovered materials.
5. Technical performance assessment.
6. Certification procedures.
7. Analysis of environmental, economic, and energy effects.
8. Assessments on a state-by-state basis of the past and present use or consideration of use of products containing recovered materials.

This information was assembled and analyzed for EPA by the contractors. The results of the analysis is a set of guideline options available to EPA. Advantages and disadvantages of the various options are presented, but no recommendations are made by the contractors.

RESEARCH PLAN

The objectives of this study were met by using a variety of research techniques. Most important were personal interviews with knowledgeable people, supplemented by library research. People contacted included employees of the Federal government, state and local governments, private companies, and trade associations.

The Federal agencies contacted included the Department of Transportation, Federal Highway Administration (FHWA), which is the key Federal agency concerned with highway construction products. Other agencies contaced are the Bureau of Indian Affairs, Forest Service, Army Corps of Engineers, Bureau of Land Management, National Park Service, and the Federal Aviation Administration. Numerous other direct personal interviews included eight state departments of transportation, trade associations representing all of the major supplier industries, contractors, individual suppliers, and many others. The American Association of State Highway and Transportation Officials was especially helpful, in that a survey of recovered material use in highway construction in each of the fifty states was conducted by the Association and the results made available for this study. All of these individuals and organizations provided information and insight in relation to the objectives previously stated.

EXECUTIVE SUMMARY

Introduction

The primary purpose of this report is to provide EPA with an information base to assist in the consideration and development of procurement guidelines. This summary is an overview of the factual material presented in this report. However, it is not possible to succinctly summarize the advantages and disadvantages of various procurement guideline options because of the complexities involved. The reader is referred to Chapters 5, 6, 7, and 8 for a discussion of guideline options for each product considered.

Magnitude of Highway Construction Markets and Potential Federal Influence

One of the first issues to be considered is whether a given class of products constitutes a significant market. If not, then Federal procurement guidelines would not be useful. Also, it needs to be determined if the potential Federal influence is significant for that market.

The recovered materials considered in this report are potential replacements for hot-mix asphalt paving, or for aggregates (including crushed stone, sand, and gravel). During the period 1970-1978, hot-mix asphalt paving was produced at an annual rate ranging from a low of 292 million tons in 1976, to a high of 376 million tons in 1978. It is projected that by 1988, the production will grow to nearly 400 million tons. In 1978 the estimated value was 4.6 billion dollars. Over the period 1970-1979, aggregate products for use in highway construction was nearly 1 billion tons each year. Both of these materials are commonly used in highway construction throughout the entire country, and clearly constitute significant markets.

The potential of Federal involvement in these markets is considered in two categories--direct Federal purchases, and Federal aid purchases. In terms of total highway construction expenditures, 87 percent of purchases in 1978 were made with Federal aid money. This year was typical. All fifty states use Federal aid money for highway construction, and in six states, virtually all highway construction was with Federal aid money. Only in one state is the level as low as 30 percent. For forty-nine states the share is 70 percent or higher. Thus, the potential of the Federal influence in highway construction markets is quite significant.

The direct Federal program is only about 1/23 of the size of the Federal aid program, and therefore is not potentially as important as the Federal aid program.

General Procurement Guideline Issues

Dynamics of the Highway Industry. In the past, there has been little incentive for state highway decision makers to aggressively pursue new highway construction materials. However, important fundamental changes have been at work since the early 1970s. Highway construction costs have trippled since 1970, while in many cases funds for highway construction and maintenance have actually declined. Also, the days of building super highways are nearly over. Now, more than ever before, highway designers must find the most cost-effective methods for highway construction and maintenance. Use of recovered materials in some instances provide cost-effective substitutes for conventional materials while providing equal or better performance. At the same time, use of these materials results in resource conservation and alleviation of solid waste problems.

Purpose of Guidelines. The EPA procurement guidelines will serve several purposes. They will encourage the use of recovered materials through Federal purchases, as specified by Congress in The Resource Conservation and Recovery Act of 1976 (as amended). This is done by providing a direct market for these materials. These purchases will increase the visibility of these products to the highway construction community, and provide documentation of the products' characteristics. It will also extend production and marketing capabilities for those products, and lead to more widely available specifications and use in non-Federally funded projects. The guidelines will serve as blueprints for procuring agencies.

It is not the intent of Congress or EPA that recovered materials be used at any cost. As a matter of fact, the intent is that the use of recovered materials be stimulated within the current general climate of competitive bidding and free market competition. To insure that this occurs, EPA has set forth criteria that products containing recovered material must satisfy in order to be condidates for inclusion in procurement guidelines. For a recovered material to be considered, it must meet the following four minimum criteria to an acceptable degree.

1. adequate supplies must be available
2. technical performance standards must be met
3. cost competitiveness with conventional products must exist
4. competitive bid situations must exist

Economic Impacts. If a free market type of competition is allowed to exist the administrative costs to the government would be insignificant. However, if guidelines are written such that an extensive administrative and monitoring system is required, the costs would be quite large. Thus, costs to the government depend entirely on how guidelines are written.

Economic impacts may result on government and on industry because of an increased market demand for certain products which could create material shortages or cause costly conversion of facilities. However, if a free market supply and demand equilibrium is allowed to exist, recovered materials will take their place in the competitive marketplace and will not result in significant increases in prices as compared to conventional materials. Also, equipment conversions will not be "forced" under such a system, and would occur only as they are perceived by the material suppliers to be economically feasible.

Specifications. A direct result of procurement guidelines will be that no specifications for which Federal agencies have drafting and review responsibilities for highway construction products will contain exclusions of recovered materials. In addition, all such specifications will incorporate the use of recovered materials to the maximum extent.

Guideline Options. In this report, four classes of recovered materials are examined in terms of specific guideline options. Those materials are power plant ash, kiln dust, rubber tires, and incinerator residue. There are five basic guideline options discussed in detail for each material. The five options are:

1. dual bids and optional bids
2. dual bids and optional bids applicable to selected states or areas
3. increase and improve educational activities
4. grants, bonuses, and other financial incentives
5. phased in, or delay in guideline implementation

A primary result of this work is a detailed consideration of the advantages and disadvantages of each of the five guideline options for each of the four recovered material categories studied. The result of those considerations only illuminated the complexity of the decision as to what action should be taken in terms of specific guidelines. The reader is referred to Chapters 5, 6, 7, and 8 for a complete discussion of the guideline options.

Two extreme guideline options were also considered. One is that no guidelines be issued. For the materials discussed in this report, it would appear that Congress requires that a guideline be issued so that "no guideline" is not an option applicable to these materials." However, EPA may decide to postpone a guideline in some cases where issuance of guidelines seems premature.

The other extreme option is a mandatory guideline that would set specific levels of recovered materials for highway construction products. There is universal objection to a guideline of this type, and general agreement that such a guideline would not increase use of recovered materials in the long run. Thus, this is not considered to be a viable option.

Viewpoints of Highway Construction Decision Makers and Material Suppliers

State Agencies. It was found that state agencies hold the key to materials decisions. These agencies are quite conservative in their approach. There is a long and detailed set of steps which a new material must follow before it is accepted as a standard material. This lengthy evaluation process has as its goal to provide highways which are soundly engineered, and which will provide good quality roads.

It was also found that state agencies resent Federal restrictions and guidelines. It is the opinion of most state officials interviewed that EPA guidelines would not be effective in increasing the use of recovered materials. This is because they are already using recovered materials or evaluating their use. However, it was the observation of the research team, that in states where a high level public official strongly supports the use of recovered materials, the process of implementation can be accelerated. But, there is no evidence that guidelines will in any way enhance those possibilities, although they may be used as a tool by such an individual.

Direct Federal Programs. The direct Federal decision makers share the states' concerns that the road construction function must always result in wise use of tax dollars, in that the paramount concern is a road that performs well and costs a fair price. They are particularly concerned that if levels of recovered materials are mandated, they may not be able to make the best decisions with regard to road construction.

Another problem incurred in direct Federal procurement is the remote location of many of the road construction projects. Most of the recovered materials are generated close to population centers. Thus, for many direct Federal projects there may be recovered material supply problems. Guidelines would have to have optional features of some fashion in order to allow for an orderly procurement process.

Indirect Federal Programs. By far the dominant highway construction activity program in the U.S. is the Federal aid program administered by the Federal Highway Administration (FHWA). This results in cost sharing by the Federal government and other public agencies in road building costs. This ranges from major U.S. highways, such as the interstate program, where the Federal cost share is 90 percent and the state share is 10 percent, to roads of lower Federal-aid classification, in particular where the Federal role is only 50 percent, and state and local governments pay 50 percent of the costs.

In this study, FHWA was identified as the primary procurement agency for which EPA guidelines would be written. They administer and monitor all Federal aid projects, and routinely require that certain procurement standards are met.

FHWA has had a generally positive attitude towards the use of recovered materials, and have acted to increase their use. However, FHWA is made up of many individuals, and there is not universal enthusiasm for use of recovered materials by every individual in FHWA. This may be particularly true at the regional level, as at least one state has reported that attempts to use recovered materials have been thwarted by the overzealous requirements placed on recovered material use by FHA district engineers. However, this appears to be the exception, as most states reported that FHWA has generally been cooperative, or helpful in their proposals to use recovered materials.

Recovered Material Suppliers. What the recovered material suppliers want is a fair test for their products. They cite the near impossibility of obtaining test strip conditions to give their product a chance in the marketplace, even if they would donate the materials and assist in the construction.

What they want the most is that their material have a chance to compete in the marketplace. They feel that if a contractor wants to bid a recovered material, and it would perform in an acceptable fashion, it should be allowed to compete. However, the real problem is on agreeing when it will perform in an acceptable fashion.

Conventional Material Suppliers. Because of procurement guidelines, the conventional material suppliers could experience substantial reductions in demand for their material in some locations because recovered materials can be substituted for their products. A reaction to this by some producers is to resort to persuasion or political pressure to try to block acceptance of recovered materials. Another approach is to attempt to influence the writing of specifications so as to unduly increase the installed cost of recovered materials.

On the other hand, some producers have taken another approach. They view recovered materials as another business venture. Thus, instead of fighting recovered materials, they have expanded into that business. This puts them in an extremely good situation, as they can supply both kinds of products to any given construction job.

Thus, the range in attitudes by the material suppliers and their trade associations can run the whole gamut from very supportive to very combative.

Use of Power Plant Ash in Highway Construction Products

General Description. Power plant ash is the solid residual resulting from combustion of coal in electric utility boilers. It consists primarily of fly ash recovered by air pollution control devices, but also consists of dry bottom ash and boiler slag. The amounts generated annually are enormous, and growing rapidly. In 1970, 39 million tons of power plant ash was generated, but this nearly doubled to 75 million tons in 1979. At present, about 11 million tons of power plant ash is being recovered for reuse in commercial products. Almost all power plant ash is generated in the region of the country east of the Mississippi, with about half of the ash being generated in six states--Ohio, Pennsylvania, Illinois, Indiana, Kentucky, and West Virginia.

In this study, five products containing power plant ash were considered:

1. Fly ash as a mineral filler in bituminous pavements
2. Power plant aggregates in base courses or in bituminous paving material
3. Fly ash in structural fills
4. Fly ash in stabilized base course materials
5. Cement stabilized fly ash bases and sub-bases

Only fly ash in stabilized base course materials was considered in depth in this study. While the other products have potential uses, they are less likely to result in widespread application and their use will be much less effective in alleviating the power plant ash solid waste problem.

Fly Ash in Stabilized Base Course Materials. The material considered here was lime-fly ash aggregate (LFA) mixtures used as a base course under bituminous (asphalt) pavements. The following conclusions were drawn concerning this material.

1. FLA has been used in this country since 1950, particularly in three states--Illinois, Ohio, and Pennsylvania. In 1979, 738,000 tons of LFA was produced, using 89,000 tons of fly ash, or 0.2 percent of the total fly ash generated. The maximum theoretical potential use of fly ash in LFA nationwide is about one-quarter of all fly ash produced.

2. Fourteen states have used LFA on at least a limited basis, and four others are presently evaluating LFA in their laboratories. One company in the Kansas City area produces a pre-blended product, in which the lime and fly ash are blended and stored prior to mixing with aggregate.

3. Assurance of quality control is a critical aspect of a successful LFA installation. This includes quality control of the fly ash and other raw materials, as well as in the production and installation of the base.

4. Eight advantages to the use of LFA were found.

   a. It is lower in cost in places where it is presently used.
   b. Strength develops in the material over long periods of time.

c. Ultimate strength is comparable to a low strength concrete.

d. LFA bases are relatively easy to install, requiring no specialized equipment.

e. Structural design coefficients are equal to or nearly equal to those of bituminous base, and substantially higher than crushed aggregate.

f. Use of LFA helps alleviate a solid waste problem.

g. LFA pavements rarely fail from fatigue.

h. LFA contains fly ash, which is a low energy-intensive material and its use helps conserve petroleum resources.

5. Four disadvantages to the use of LFA were found.

a. LFA cannot be installed during cold weather, thus reducing the construction season.

b. LFA may not be suitable for reconstruction projects where maintenance of heavy traffic is important.

c. Quality control must be stringently observed.

d. Many engineers view fly ash as a waste, not a product, and are therefore reluctant to specify its use.

6. Both guide specifications and state specifications for routine use exist.

7. It would appear that the use of LFA produces potentially significant solid waste and energy benefits when compared to asphalt concrete. However, the dust problem created by materials handling may cause some adverse impact in terms of air quality. Water pollution is not significant, and the processing wastes generated are not important in view of the considerable alleviation of solid waste resulting from the use of fly ash. There is no indication that there is a potential problem arising from leaching of toxic constituents from LFA.

8. In objectively weighing the advantages versus the disadvantages of LFA base materials, on balance, the good points of this material definitely outweigh its bad points. It is a proven fact that, if this material is designed, produced, and placed properly, it performs well. It is a versatile product, having been produced with almost every kind of aggregate and dozens of different sources of fly ash. The obvious advantage that LFA base offers in dramatic cost savings is, in and of itself, a compelling reason enough to justify widespread use of this mateiral. Therefore, from a technical and economic standpoint, use of LFA base is not only justifiable, but also very beneficial.

Use of Kiln Dusts in Highway Construction Products

Kiln dusts are the product of air pollution control in cement and lime plants. These dusts result from the heating of limestone to produce lime, or from the heating of portland cement raw materials (limestone, silica, alumina, and iron oxide) to produce a cement clinker. The kiln dusts vary in chemical composition, but have a high calcium composition and resemble finely divided lime or cement in appearance. Currently, 10 to 14 million tons of kiln dusts are being disposed of annually. This is clearly a significant national solid waste problem, but is only about one-fifth the volume of power plant ash.

Cement and lime plants are located throughout the U.S., so that kiln dust generation is more uniformly distributed than power plant ash. However, production in five states--California, Texas, Missouri, Michigan, and Pennsylvania--account for 44 percent of the national total.

Kiln dusts have only become a significant waste problem in the past ten years, largely because stringent pollution control measures were not widely used previously. Thus, markets are just beginning to be developed for kiln dusts. In this study, the focus was on kiln dusts as a replacement for lime in stabilized base materials. However, kiln dusts can frequently be used as a lime replacement in a variety of relatively minor highway construction applications, such as use as a soil stabilizer.

The following conclusions were reached concerning the use of kiln dusts as a replacement for lime in stabilized base materials (kiln dust-pozzolan-aggregate mixtures).

1. At the present time this product is patented, and licenses are currently being made available to manufacture and install this product. The lack of commercial availability would create serious problems for a guideline written to encourage widespread use right now. However, this product will likely be widely available in the near future.

2. Quality control of kiln dusts is a critical problem because of changes in raw material and changes in plant operation at cement and lime kilns can cause unacceptable variations in kiln dust composition. However, frequent testing of dusts and close cooperation between dust consumers and plant operating personnel can result in a high quality product.

3. Only five field tests have been installed, with no large commercial applications to date. However, a comprehensive testing and evaluation program has been recently initiated by the Federal Highway Administration.

4. Tests have been performed to define technical parameters of kiln dust-fly ash-aggregate mixtures. The laboratory data, which is mostly compressive strength testing of various compositions, shows a striking similarity to that obtained with proven hydrated lime-fly ash-aggregate road base compositions. This helps to substantiate the viability of using kiln dust in these applications.

Five field installations of road base containing kiln dust prove that the material can be successfully used. It is obvious, however, that there are significant gaps in the information that is available. This is particularly true with regard to durability. There is also a need for larger, fully documented experimental field installations that will provide the type of information that will be convincing to potential users of road base materials.

5. At this time, there are no guide specifications or specifications for routine use.

6. It is quite clear that the energy and environmental impact of using kiln dusts is quite positive. Use of fly ash and kiln dusts in pozzolanic bases can result in 2.6 million pounds of waste use for each mile of 2-lane road. In addition, 1.2 billion Btu of energy may be saved. Also, air and water pollution may be reduced a small amount as a side benefit. Thus, use of these waste materials clearly results in substantial benefits.

Use of Rubber Tires in Highway Construction Products

One of the most persistent and troublesome problems facing municipal landfill operators is rubber tires, which cause numerous operational problems. Nationally, 2.7 million tons of rubber tires are discarded annually. While the largest volumes of waste occur in major population centers, virtually every landfill in the country receives some rubber tires.

In this study utilization of waste tires in asphalt-rubber compositions for highway construction was evaluated. The two primary products are stress absorbing membranes (SAM) and stress absorbing membrane interlayers (SAMI). The SAM is usually used in the form of a thin layer on top of a pavement, frequently as a "chip seal." The SAMI is a thin layer of asphalt-rubber which is subsequently overlain with a conventional asphalt concrete wearing course. These uses consume approximately 4 tons of waste tires per lane-mile of highway.

The use of asphalt-rubber has grown from an estimated 500 tons in 1970, to 33,000 tons in 1980. Although it is potentially available anywhere in the country, most of the miles of installed product are in Arizona and Texas, with significant mileage also being installed in Saskatchewan Province, Canada. At present, these products are covered by patents.

The following conclusions were drawn with regard to asphalt-rubber SAM and SAMI applications.

1. Under FHWA sponsorship, at least 23 states have participated in asphalt-rubber demonstrations or test strips. However, only in Texas and Arizona is asphalt-rubber now being used routinely.

2. It is concluded that asphalt-rubber is unique in controlling cracking when used on top of a cracked pavement and then covered with a thin overlay. It is also concluded that asphalt-rubber chip seal can be a successful surface treatment on severely cracked pavements where the only other option seems to be reconstruction, although there is a difference of opinion as to whether chip seal should be used on high-speed roads where loose chips could create a hazard.

3. At the present there are not guide specifications except for those written by the producers. However, Arizona has specifications for routine use, and ASTM has formed a committee to develop guide specifications.

4. Although the evidence is strong that asphalt-rubber is a technically proven material, this does not mean that the material is universally acceptable yet for routine applications in the U.S. In fact, many of the 8,000 to 10,000 lane-miles of asphalt-rubber have given disappointing performance. In most cases, this can be related to lack of experience of contractors and engineers, and because there are still many aspects of asphalt-rubber not fully understood. There is a strong need for both additional research and additional availability of trained personnel.

5. On a first cost basis, asphalt-rubber chip seals are more expensive than conventional chip seals. However, there is insufficient experience to allow a calculation of life cycle cost although it is quite possible that the result would be favorable to asphalt-rubber. A cost comparison for SAM or SAMI to conventional materials is quite difficult because of the lack of a conventional material that performs in the same manner. It has not been established whether a SAM or SAMI should be compared to conventional overlay, or whether asphalt-rubber delays reconstruction, or both. By some calculations, asphalt-rubber is less expensive, while others will not agree. Thus, there is insufficient data at this time to determine an accurate cost comparison.

6. Asphalt-rubber used as a substitute for asphalt concrete probably results in less energy and environmental impact. Thus, it is concluded that use of asphalt-rubber is desirable from that point of view, at least to the degree that our examples used in this study are realistic. The problem is that a precisely determined comparison can not be formulated because of the unique properties of asphalt-rubber.

Use of Incinerator Residue in Highway Construction Products

Over 90 percent of the municipal solid waste in this country is landfilled as a means of final disposal. However, a growing number of municipalities are employing thermal processing to greatly reduce the volume of the waste stream. The remaining residue is mostly glass and metal, with small amounts of minerals also included. An examination was made of three potential highway construction applications of unfused incinerator residue. They are: bituminous base course, wearing surface, and lime stabilized base and sub-base. In all cases, incinerator residue was used as an aggregate, usually in a mixture of conventional aggregate and incinerator residue. That is, it is not a pozzolanic material and its reactivity is quite low.

In 1980, there were 60 municipal incinerators operating, generating 2.5 million tons of residue. This volume is much smaller than power plant ash or kiln dusts, but it is generated in densely populated areas with serious waste disposal problems. Thus, incinerator residue is considered a significant solid waste problem for those locations.

The following conclusions were reached concerning the use of incinerator residue in the products mentioned above.

1. One of the most important features of an incinerator residue is the gradation of particle sizes, and the laboratory work has carefully evaluated this. In order for a construction product to perform successfully there must be a wide range of aggregate sizes included, ranging from very fine material (dust) which has a particle size well under 0.1 millimeter to gravel size pieces as large as one-half inch.

One important factor associated with this gradation is that the amount of asphalt cement required in a bituminous mix must be adjusted accordingly. If too many fine particles are present in an aggregate, the consumption of asphalt cement goes up.

It has been found that in most cases, incinerator residue requires more asphalt cement than conventional aggregates. While a conventional bituminous mix may be 4 to 5 percent asphalt cement, when incinerator residue is used to replace approximately one-half of the aggregate, the asphalt cement required may be up to 8 percent in order to achieve optimum particle coating. Thus, the asphalt cement requirement may double if incinerator residue is used.

2. A problem encountered with using incinerator residue in pavement applications, is that a great amount of material quality control is needed. This is because only high quality residues may be used in pavement applications. Having to carefully monitor the residue which is to be used in pavement applications arises from the incineration process itself. Factors affecting the quality of the residue are time of combustion, temperature of combustion, and turbulence during combustion. These three factors are normally of little significance during municipal incineration operations but greatly affect residue quality.

3. A disadvantage of using incinerator residue in lime stabilized base and sub-base applications is that the material requires a time period of approximately 3 days before placement of the wearing surface may be performed. This is required to eliminate potential damage to the wearing surface by hydrogen gas pressures that will develop in incompletely cured incinerator mixes. These products are presently covered by patents that apply to residue from rotary kiln incinerators.

Another disadvantage of incinerator residue/lime material is it does not appear to perform well under laboratory freeze-thaw testing, though high 180-day compressive strengths of +700 pounds per square inch and good California Bearing Ratio values have been attained for certain projects (i.e., Northbrook, Illinois).

4. Test results from two experimental sections indicate that bituminous wearing surfaces containing incinerator residue as a partial aggregate replacement show slightly better skid resistance characteristics than their adjacent control pavement sections. This may be due to differential wearing of the particles of residue and aggregate.

5. Eleven field tests of products using incinerator residue have been documented. In most cases, the results of evaluations have been favorable. No large scale installations of products using incinerator residue have been made.

6. Because of the quite low rate of use of incinerator residue in highway construction products, no guide specifications exist, and no states routinely use this material.

7. In one recent study performed for the Federal Highway Administration, the economic feasibility of using incinerator residue as an aggregate replacement in highway construction was assessed by using engineering estimating techniques. The results of that study show that if a credit for avoidance of landfilling is used, that unfused incinerator residue is an economical alternative in some cases. Important variables include the availability of residue of acceptable quality, and costs to transport the residue to the sites needed. An important factor is the nearness of the construction sites to the virgin aggregate source and to the site of residue generation. Basically, the economics of transport restrict the use of incinerator residue to the regions of a metropolitan area most remote from the virgin aggregate sources. However, in any event, it is unlikely that incinerator residue could be used at distances in excess of 40 miles from the incinerator, and in most cases the construction site would have to be a distance of 20 miles or less.

8. The increased requirement of asphalt cement for asphalt-incinerator residue-aggregate base courses renders that option by far the most energy intensive option. This option may or may not result in more air pollution than conventional asphalt concrete, depending on the handling of the dust problem associated with incinerator residue. Because of the significant use of asphalt cement, the asphalt-incinerator residue-aggregate option also results in more water pollution.

These somewhat negative energy and environmental conclusions discussed here are balanced to some degree with the fact that the use of incinerator residue may result in a significant alleviation of municipal solid waste streams. In addition, landfilled incinerator residue results in leachate under some conditions that would be classified as hazardous. The stabilization and/or encapsulation of incinerator residue with asphalt cement probably renders the leachate non-hazardous.

The analysis of pozzolanic stabilized base (lim kiln dust-incinerator residue) results in less ambiguous conclusions. It results in less energy and environmental impact than other options so that its use is quite desirable from that point of view.

REPORT ORGANIZATION

The results and findings of this study are included in two volumes. This volume is Volume 1 and is a summary and discussion of the findings. Chapter 2 of this volume is a discussion of the highway construction products markets. Chapter 3 is a discussion of guideline issues, and Chapter 4 presents various viewpoints of guidelines. Chapters 5, 6, 7, and 8 are detailed analyses of each recovered material and the guideline options for each material. Volume 2 is an appendix which contains detailed discussions of technical issues, and the energy and environmental analyses.

Chapter 2

MAGNITUDE OF HIGHWAY CONSTRUCTION MARKETS AND POTENTIAL FEDERAL INFLUENCE

INTRODUCTION

There are two important supply and demand issues which must be analyzed in consideration of a procurement guideline. It must be shown that the highway construction market is significant, and it must be shown that Federal purchasing power is substantial for the products studied. These two issues are discussed in this chapter.

U.S. CONSUMPTION OF HIGHWAY CONSTRUCTION MATERIALS

The recovered materials considered in this study are primarily used in stabilized bases for flexible pavements or as flexible wearing surfaces. Thus, the products they replace are bases made from aggregate, or hot mix paving material (asphalt concrete) which is comprised of a mixture of aggregate and asphalt cement; and wearing surfaces made from asphalt concrete. The conventional materials considered here, then, are aggregates and asphalt concrete.

Hot Mix Paving (Asphalt Concrete)

In the United States over 93 percent of all paved roads, streets, and highways are surfaced with asphalt concrete. This amounts to approximately 1.6 million miles (Reference 2-1).* In the last several years over 30 million tons of asphalt cement and 350 million tons of aggregate have been consumed annually in the production of hot mix asphalt paving (Reference 2-2). However, not all of this is used for highway construction. As Table 2-1 shows, only 46 percent of the total asphalt produced is used in highway construction. The remainder is consumed in local roads, parking lots, driveways, and other miscellaneous applications. Figure 2-1 displays the relative use by each of these categories.

The number of miles of existing streets and highways has been steadily growing for many years, but recent drops in revenues for highway construction has led to a decline in new routes and new construction. Spokesmen from the asphalt industry and government highway departments see the emphasis shifting from new construction in the future, to the resurfacing and reconstruction of existing roads and highways. Table 2-2 shows the total asphalt paving production for the years 1970 up to a 1985 projection. The total production is reported in terms of construction and resurfacing categories which are plotted on Figure 2-2. As can be seen, total asphalt paving mix demand will continue to grow over the years with resurfacing applications consuming larger amounts of the total input. Thus, the demand for highway base construction materials will likely decline in the foreseeable future, while demand for wearing course materials will likely increase. However, even with a modest decline in new construction, the amounts of material are quite large and represent significant markets.

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* See references at the end of the chapter.

Table 2-1

ANNUAL PRODUCTION OF HOT-MIX ASPHALT PAVING
(Millions of Tons)

Year	Production	Interstate	State Highway	City or County	Parking Lots Driveways
1970	308.8	40.1	101.9	74.1	74.1
1971	317.0	44.4	98.3	76.1	79.3
1972	324.8	52.0	97.4	68.2	90.9
1973	364.2	43.7	98.3	91.1	116.5
1974	343.4	37.8	103.0	85.9	99.6
1975	293.8	38.2	94.0	70.5	76.4
1976	292.1	29.2	99.3	70.1	78.9
1977	313.3	34.5	97.1	78.3	78.3
1978	376.0	37.6	116.6	97.8	94.0

Projected: (Average of minimum needs and demand)
1985 398 (Resurfacing - 251 million tons)
(New Construction - 147 million tons)

Source: Reference 2-2.

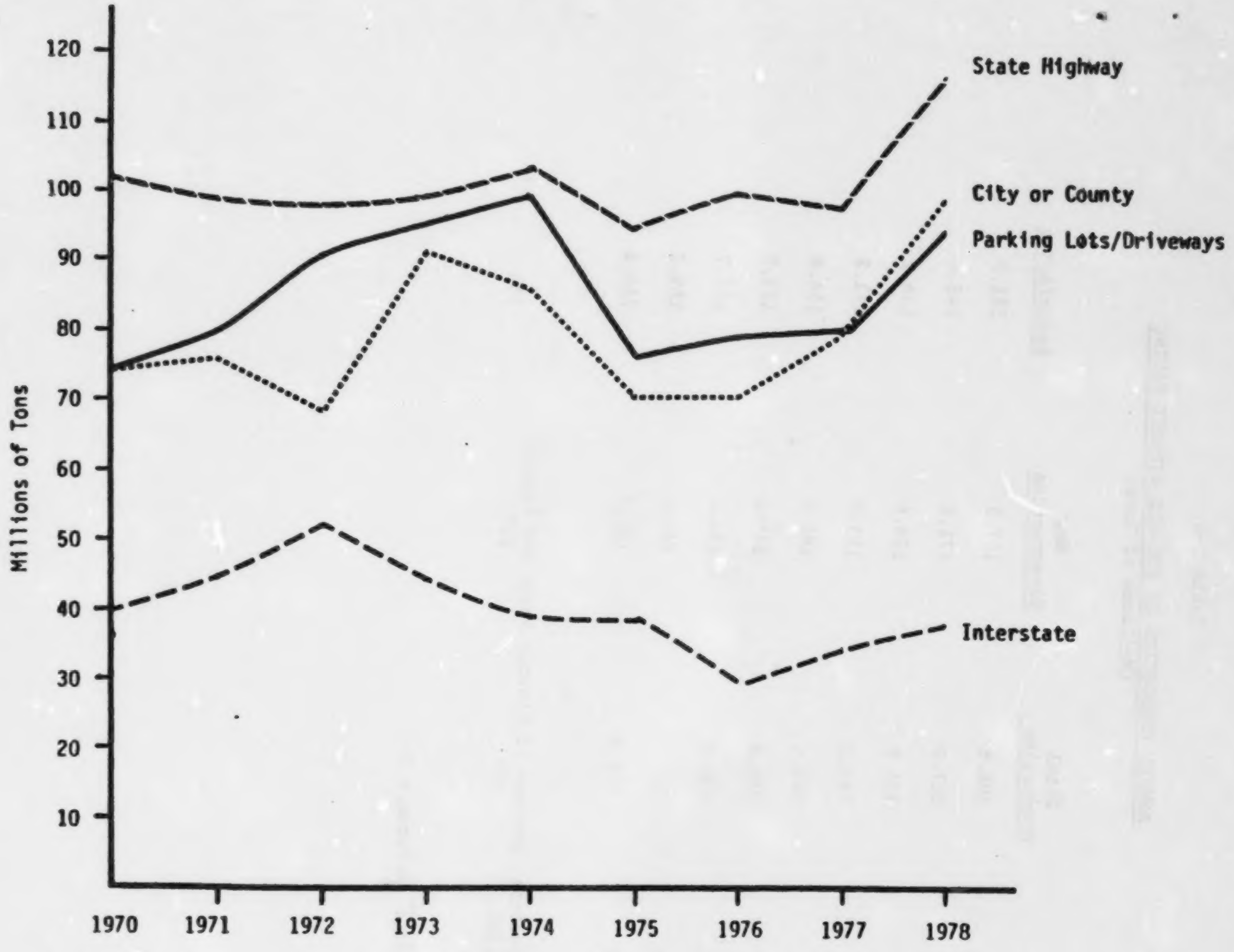

Figure 2-1. Annual production of hot-mix asphalt paving.

Table 2-2

ANNUAL PRODUCTION OF HOT-MIX ASPHALT PAVING
(Millions of Tons)

Year	Total Production	New Construction	Resurfacing
1970	308.8	157.5	151.3
1971	317.0	171.2	145.8
1972	324.8	178.6	146.2
1973	364.2	193.0	171.2
1974	343.4	185.4	158.0
1975	293.8	138.1	155.7
1976	292.1	134.4	157.7
1977	313.3	144.1	169.2
1978	376.0	165.4	210.6
Projected: Average of Minimum Needs and Demand)			
1985	398	147	251

Source: Reference 2-2.

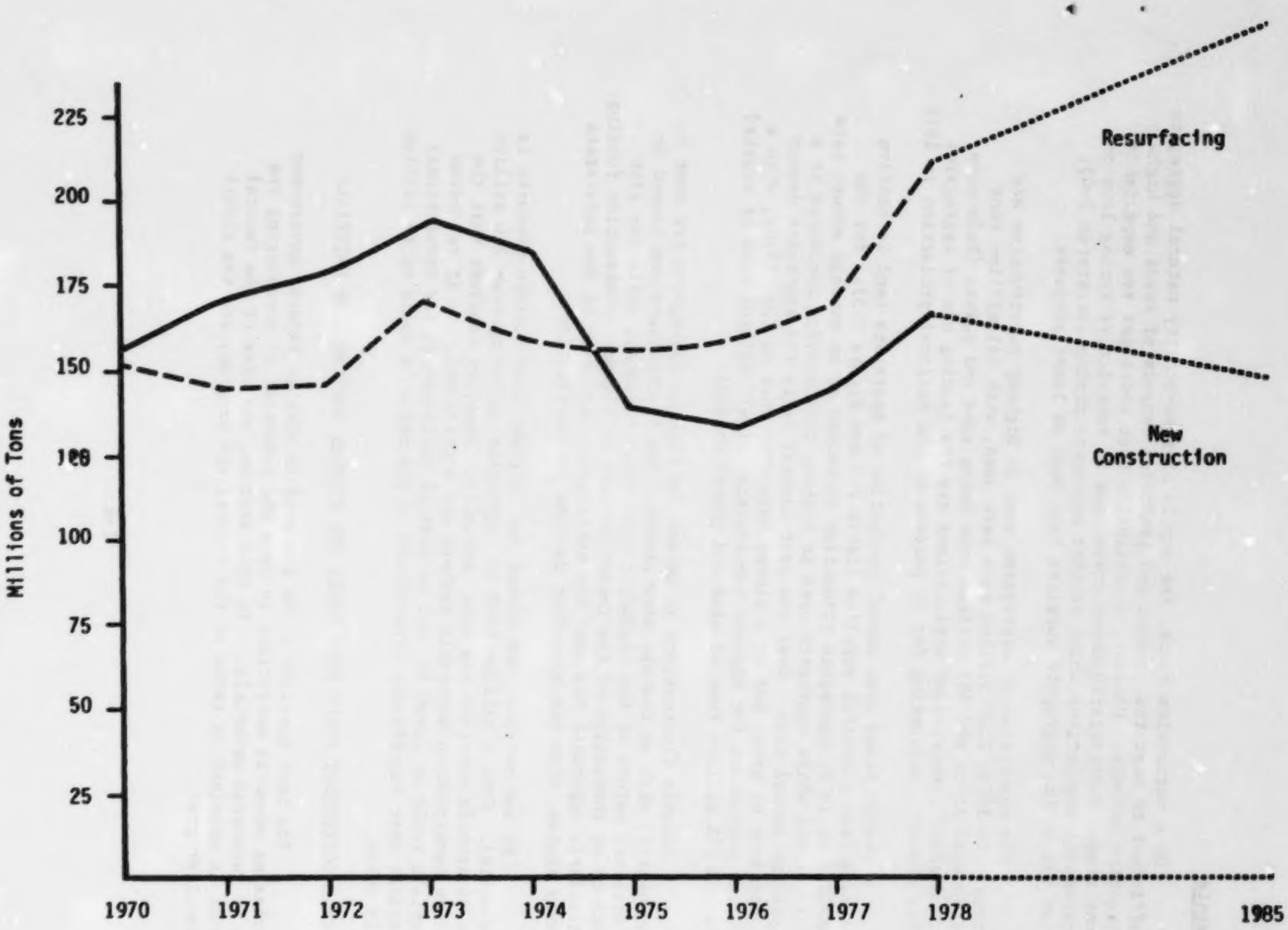

Figure 2-2. Annual production of hot-mix asphalt paving by use.

Aggregate

On a nationwide basis, the supply of good-quality natural aggregate is sufficient to meet the present and predicted demands of roads and highway construction markets. However, occasionally spot shortages are experienced in some areas, particularly urban areas, due to restrictive zoning laws or environmental regulations which inhibit aggregate mining (Reference 2-4). But, on the whole, aggregate supplies have been at least adequate.

The quantities of aggregates used in highway construction are enormous. In 1979, 1.07 billion tons were used, with 641 million tons being crushed stone and 433 million tons being sand and gravel (Reference 2-2). Highway construction applications are the leading use of aggregates in this country, accounting for 51 percent of the national production in 1979.

Trends based upon annual production of aggregate tend to confirm there have been plentiful supplies (Table 2-3 and Figure 2-3). For the years 1970 to 1979, aggregate production increased at an average annual rate of 3.1 percent while aggregate used in highway construction increased at a 4.6 percent annual rate. Over the next several years the aggregate demand will continue to grow, but at a slower rate than that of the 1970s, with a projected production for highway construction of 677 million tons of crushed stone and 471 million tons of sand and gravel in 1985.

Sizable fluctuations in demand for highway aggregates are seen to occur yearly, with an overall slow growth. The fluctuations are caused by the cyclical nature of the highway construction industry, while the slow growth is an indication of the recent decline in highway construction funding. Particularly important has been the nearing of completion of the interstate freeway system, with the attendant decline in construction.

By any measure, the market for highway construction products is substantial. Over 1 billion tons of aggregate including over 250 million tons in asphalt concrete are used annually. Thus, we conclude that the highway construction materials markets are significant, and if recovered materials could at least be used as partial replacements for conventional materials that significant alleviation of the nation's solid waste problem could occur.

FEDERAL GOVERNMENT PURCHASING POWER FOR HIGHWAY CONSTRUCTION MATERIALS

The next question to be answered is whether Federal government purchasing power is sufficient to have the potential of encouraging the use of recovered materials. In this section, the size of the Federal market is examined in terms of the Federal aid program, and the direct Federal program.

Table 2-3

TOTAL ANNUAL PRODUCTION OF AGGREGATE
(Millions of tons)

Year	Crushed Stone Production	Crushed Stone Total Used in Highway Construction	Sand and Gravel Production	Sand and Gravel Total Used in Highway Construction
1970	868	441	944	503
1971	874	445	919	446
1972	919	491	914	411
1973	1,059	589	984	451
1974	1,042	571	905	425
1975	900	504	789	368
1976	900	493	885	405
1977	954	542	929	388
1978	1,056	604	996	426
1979	1,120	641	979	433
Projected: 1985	1,200	677	1,020	471

Source: Reference 2-2.

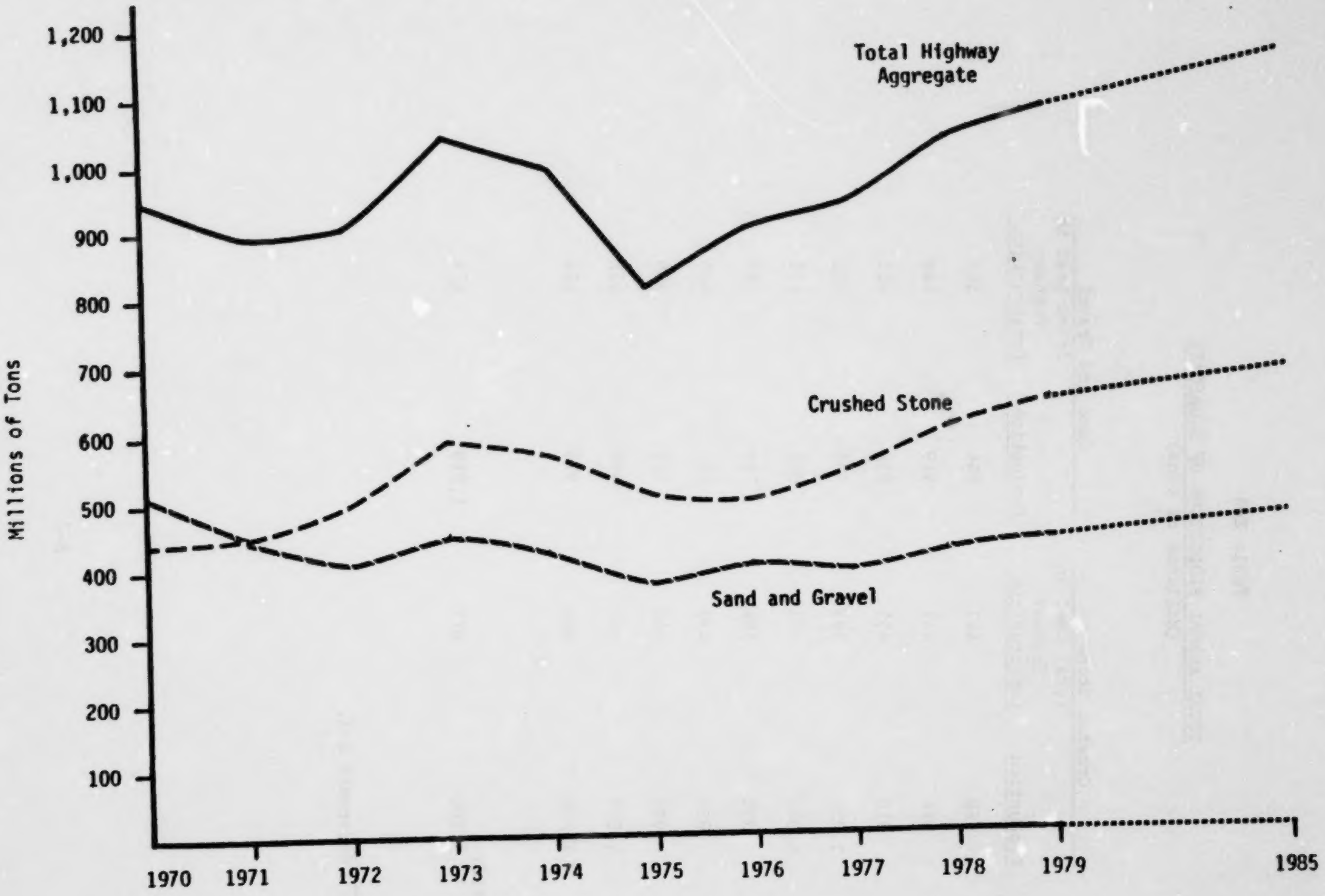

Figure 2-3. Total annual production of aggregate used for highway construction.

Figure 2-4 is a summary of the capital outlay expenditures for highway construction in the U.S. for 1969 through 1979 (Reference 2-5). The values are plotted in 1967 constant dollars so as to compensate for the effects of inflation and give a measure more closely related to quantities of materials consumed. As can be seen, the Federal aid dollars completely dominate the picture for every year. This money is generally offered to the states on a shared basis, where the Federal aid usually comprises 50 to 90 percent of the total funding of each road construction project. This is followed by the "other" category which is state, county, and local government expenditures. Finally, direct Federal aid is the smallest sector of the market. This is generally construction on Federally owned or controlled lands, such as parks, reservations, military installations, and airports.

Table 2-4 is a more detailed listing of the capital outlays showing the Federal influence in each state for 1978. In that year, the average Federal contribution was 87 percent, but the range was from 30 percent to 100 percent. The Federal aid portion averaged 84 percent, other sources were 13 percent, with direct Federal accounting for only 3 percent.

The data shown in Figure 2-4 are replotted in Figures 2-5, 2-6, and 2-7 in terms of 1967 constant dollars. It can be seen that the time trends are nearly identical. They show a relatively consistent decline in constant dollar expenditures, with a slight upturn in 1978. Projections past 1979 were not found because of the great uncertainty in the political future of highway construction. However, spokesmen of the supply industries do not expect to see any radical shifts in the near future. The likely long term prospects will be a gradual growth in current dollar expenditures, but this will not keep pace with inflation. Thus, further erosion in terms of constant dollar volume may continue.

In any event it is clear that the Federal aid program has considerable control over use of highway construction funds. The ability to require specifications for most new road construction means that the potential to encourage the use of recovered materials is significant. However, the direct Federal program is only about one-thirtieth as large and has less potential to significantly affect solid waste reuse.

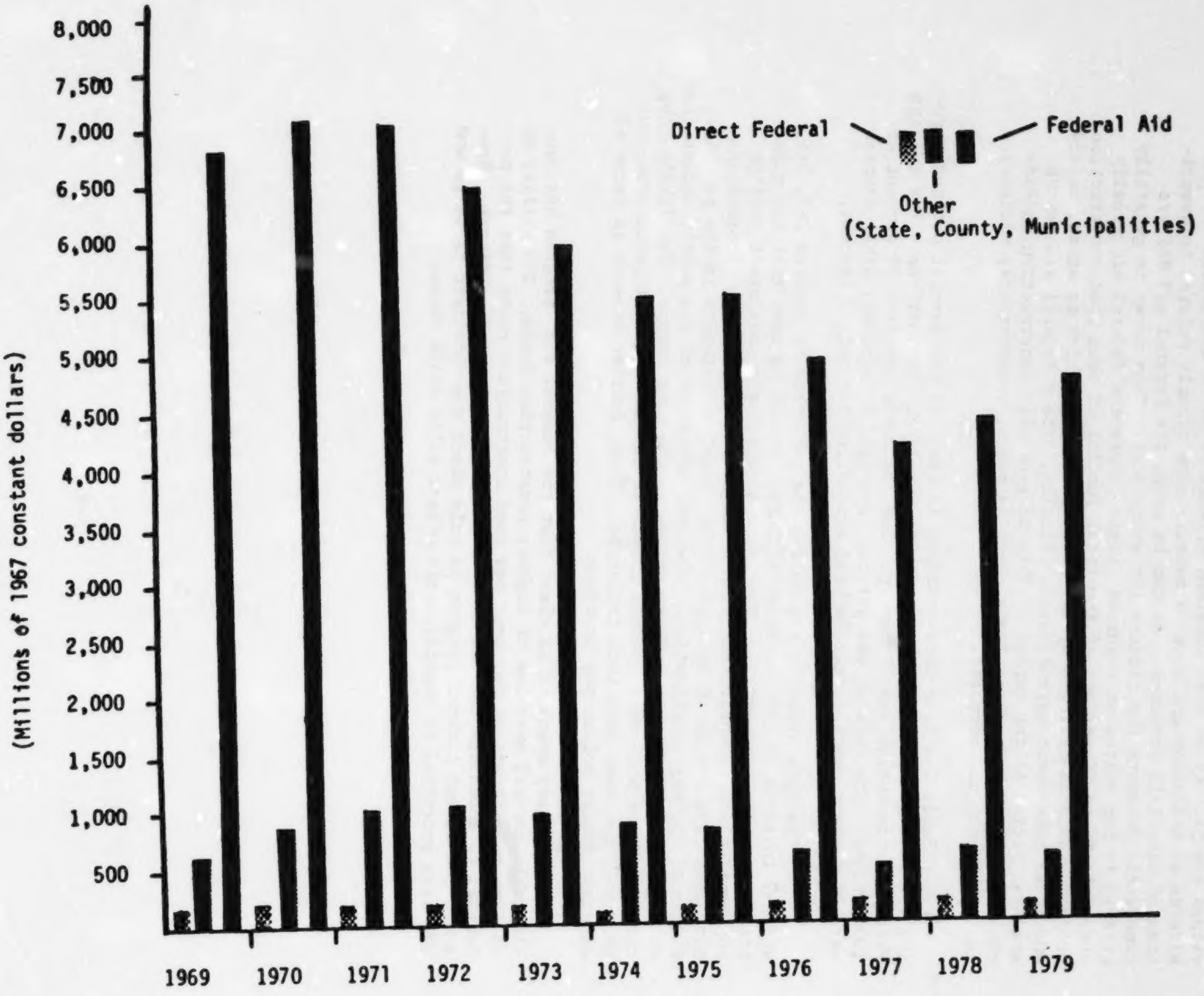

Figure 2-4. Capital outlay expenditures 1969 to 1979 in constant dollars.

Table 2-4

1978 - CAPITAL OUTLAY EXPENDITURES
(millions of dollars)

	Direct Federal	Federal Aid	Other	Total	Percentage of Federal Dollars
Alabama	1.110	262.700	26.235	290.045	91
Alaska	11.646	96.721	6.625	114.991	94
Arizona	25.332	167.309	-	192.641	100
Arkansas	2.991	156.763	18.614	178.368	90
California	77.153	400.270	106.525	583.948	82
Colorado	13.626	148.617	6.129	168.372	96
Connecticut	.236	73.028	31.022	104.286	70
Delaware	-	44.793	10.209	55.002	82
District of Columbia	3.582	22.460	6.415	32.457	80
Florida	1.196	336.264	139.127	476.587	71
Georgia	1.829	300.839	108.827	411.495	74
Hawaii	1.358	56.520	.036	57.914	100
Idaho	27.823	63.153	2.721	93.697	97
Illinois	1.544	406.943	111.302	519.789	79
Indiana	1.958	158.320	4.807	165.085	97
Iowa	.111	226.830	6.208	233.149	74
Kansas	2.937	171.948	.025	174.910	100
Kentucky	1.958	306.619	90.094	405.671	78
Louisiana	1.912	301.309	47.321	350.542	87
Maine	1.471	54.509	12.721	68.701	82
Maryland	.911	108.315	4.742	113.968	96
Massachusetts	.532	81.613	21.261	103.406	80
Michigan	2.350	267.905	-	270.255	100
Minnesota	3.298	290.533	.555	294.386	100
Mississippi	3.539	173.082	18.233	194.854	91
Missouri	6.451	282.371	2.694	291.516	99
Montana	23.168	95.906	1.972	121.046	98
Nebraska	.435	106.594	6.347	113.376	95
Nevada	2.860	66.782	3.261	72.903	96
New Hampshire	.754	39.864	14.656	55.274	74
New Jersey	.918	113.999	34.039	148.956	77
New Mexico	21.866	94.469	3.228	119.563	97
New York	.005	781.131	44.405	825.541	95
North Carolina	3.032	94.792	228.413	326.237	30
North Dakota	2.759	64.248	3.302	70.309	95
Ohio	2.661	339.292	17.317	359.270	95
Oklahoma	3.959	124.868	7.365	136.192	95
Oregon	54.030	115.001	1.101	170.132	99
Pennsylvania	6.458	244.241	49.359	300.058	84
Rhode Island	-	16.272	-	16.272	100
South Carolina	1.428	126.890	17.178	145.496	88
South Dakota	7.212	57.867	3.568	68.647	95
Tennessee	3.915	250.265	20.587	274.767	93
Texas	6.222	655.822	51.342	713.386	93
Utah	9.206	66.727	16.971	92.904	82
Vermont	.536	26.958	4.229	31.723	87
Virginia	2.199	445.560	17.820	465.579	96
Washington	25.757	242.268	13.502	281.527	95
West Virginia	5.061	182.561	75.922	263.544	71
Wisconsin	3.717	176.863	11.884	192.464	94
Wyoming	6.216	82.437	3.424	92.077	96
Total	421.061	9,571.411	1,433.640	11,426.112	87.4

Source: Reference 2-5.

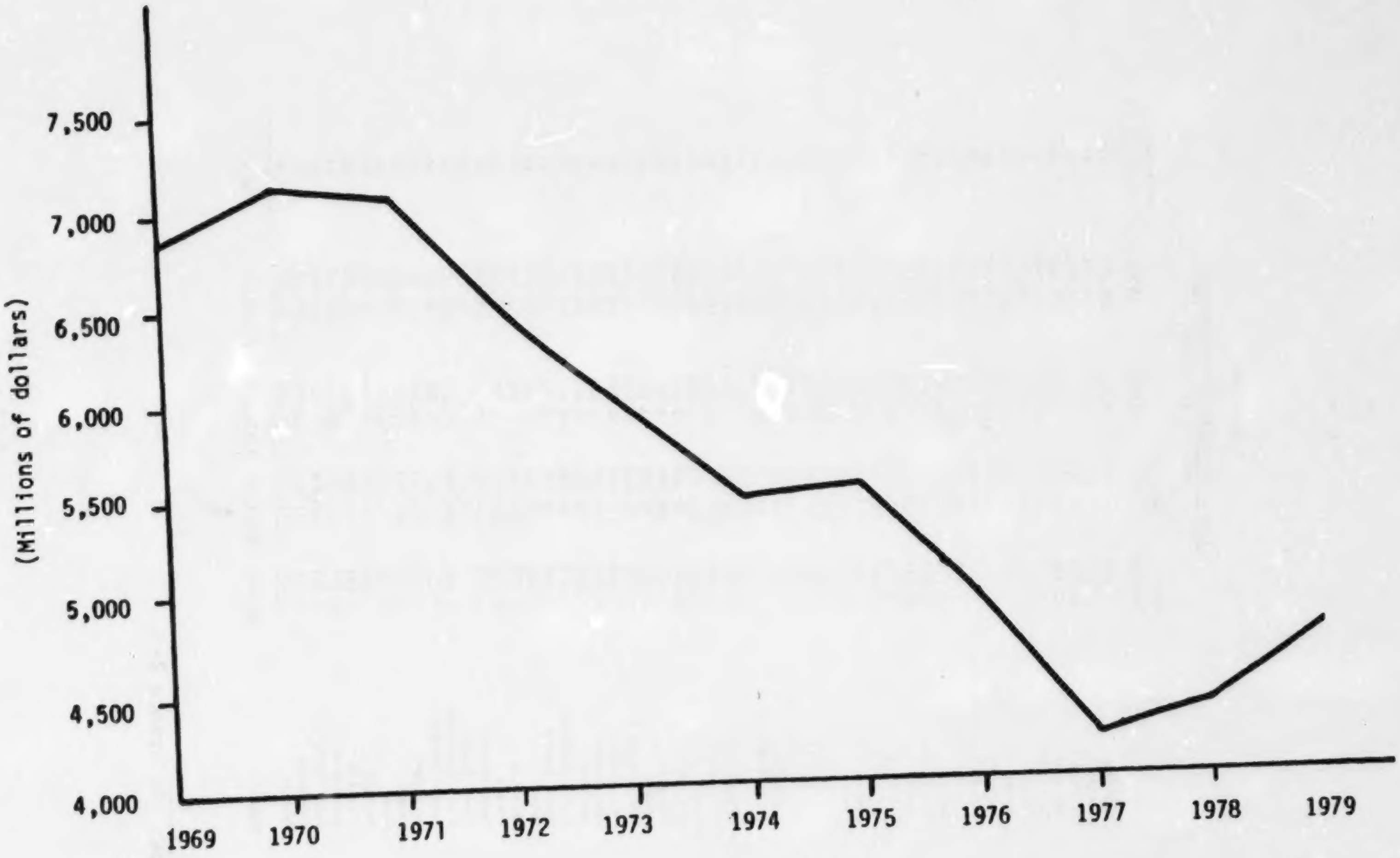

Figure 2-5. Capital outlay Federal aid in constant 1967 dollars. Actual expenditures are higher than shown.

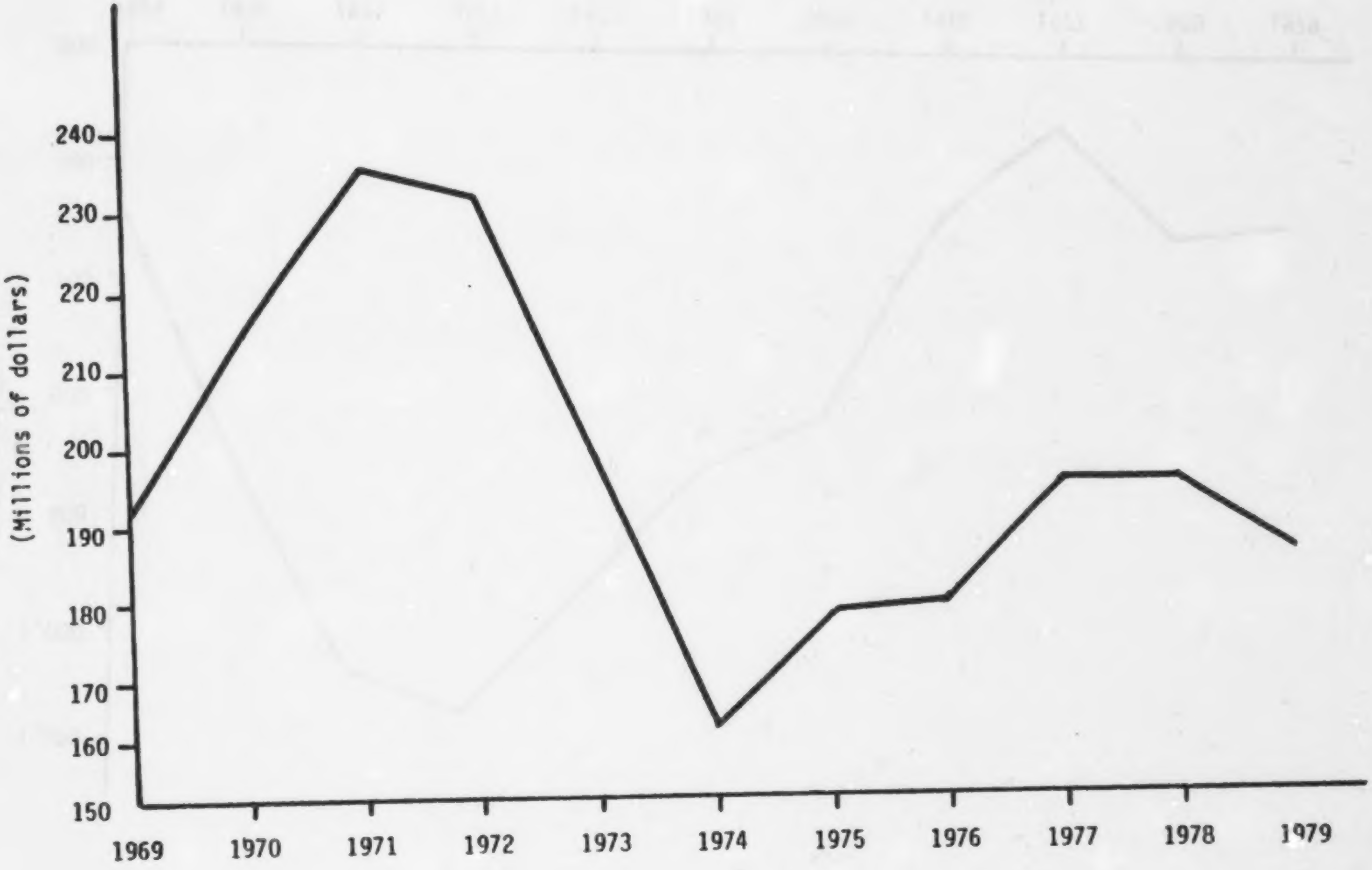

Figure 2-6. Capital outlay direct Federal in constant 1967 dollars. Actual expenditures are higher than shown.

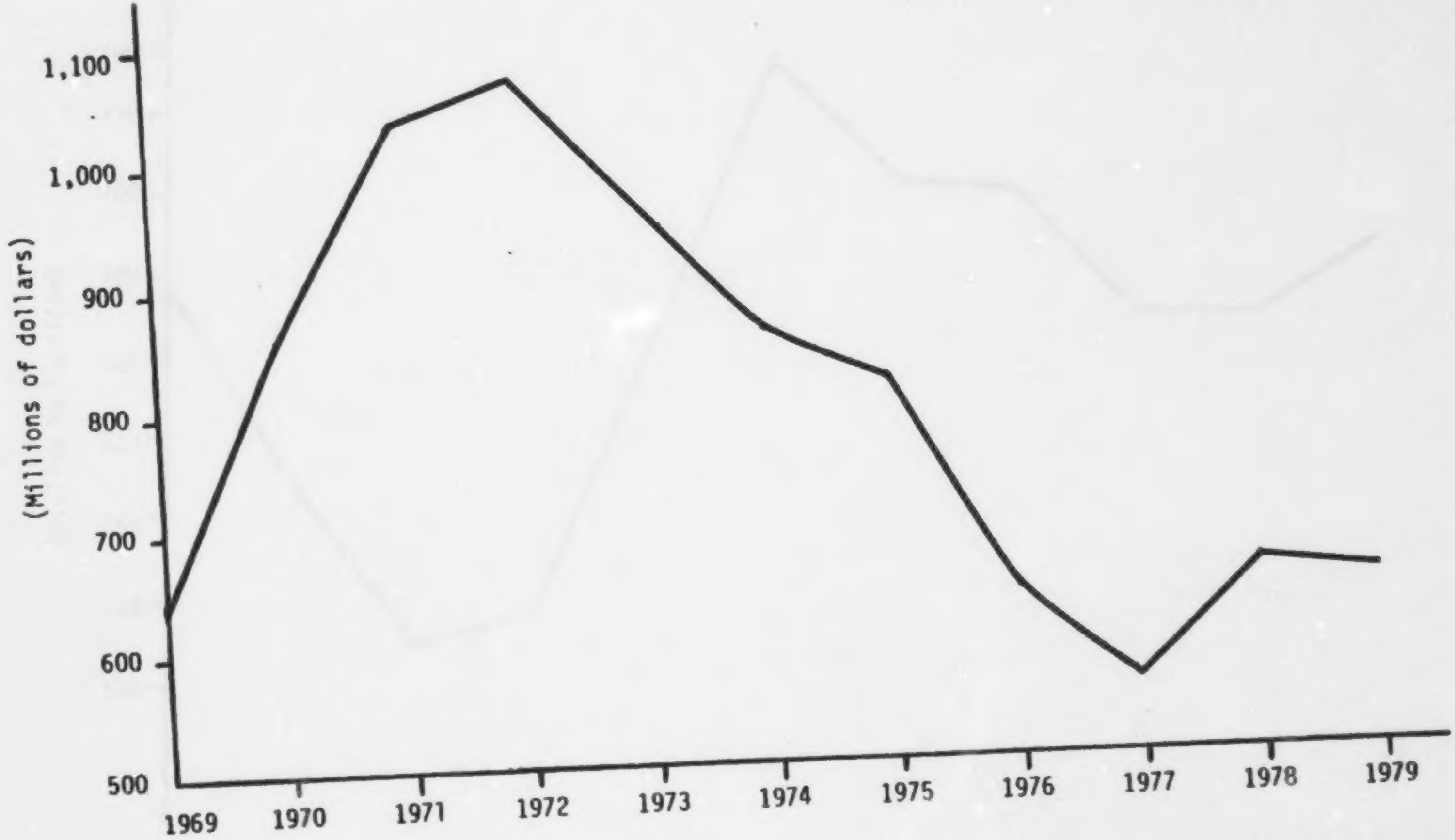

Figure 2-7. Capital outlay for other uses in constant 1967 dollars. Actual expenditures are higher than shown.

Chapter 2

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Chapter 3

PROCUREMENT GUIDELINE ISSUES BACKGROUND INFORMATION ON THE DYNAMICS OF THE HIGHWAY INDUSTRY

The U.S. highway industry presently finds itself in a situation where significant changes in long established policies and operating procedures are taking place. The impetus for such changes has gradually come about during the past 10 years and is a consequence of the following factors:

(1) Increased costs of petroleum have caused gasoline prices to soar, resulting in reduced fuel consumption by the American public and the gradual use of more fuel efficient automobiles. The net effect is a decline in motor fuel tax revenues at the Federal and state levels. Some states are also faced with drastic cutbacks in operating revenues because of past bond indebtedness.

(2) Inflationary pressures have forced the cost of constructing transportation facilities to triple nationwide since 1970, with even higher cost increases observed in many parts of the country.

(3) Resources such as stone and cement, which at one time seemed inexhaustible, are now in short supply in some areas due to restrictive zoning, environmental regulations, and urban sprawl. Even in areas where a sufficient supply of such resources is available, the expense involved in transporting these materials, which is directly related to fuel cost increases, has escalated dramatically.

(4) Increased numbers of vehicles on the nation's roads and streets have created an even more obvious need for maintenance.

For these reasons, it is now apparent that the present system of funding highway improvements by a fixed gasoline tax can no longer keep pace with the rising costs for maintaining, or rebuilding, highway facilities, much less constructing new highways. There are simply less highway dollars available today, while at the same time per mile costs for highway construction and maintenance are three times greater than they were ten years ago.

In 1956, the U.S. embarked on the most ambitious public works program ever: the construction of the interstate highway system. Today, this program is about 90 percent completed. With the advent of the interstate system came the introduction of the 90:10 Federal funding concept, where the Federal government provided 90 percent of interstate highway construction costs and individual state governments were responsible for only the remaining 10 percent of original construction. However, state and local governments are responsible for 100 percent of the maintenance costs on completed highway facilities.

The highest design and construction standards were maintained for these highways, regardless of the costs involved in most cases. Because the Federal government provided 90 percent of the funding, Federal highway officials were able to more or less standardize highway designs for interstate-type facilities by requiring that states adhere to AASHTO (American Association of State Highway and Transportation Officials) standards as a minimum. As a result, there was little or no incentive on the part of an individual state highway department or its consultants to be cost conscious or innovative in designing interstate or primary highway facilities.

Because the days of building super highways are now all but over, the emphasis in highway construction is now shifting towards maintaining, improving, and making more efficient use of the facilities we now have, rather than building more new highways. In keeping with this new direction, the old philosophy that has predominated highway planning and design decision making since World War II must now, of necessity, be re-evaluated.

During the past decade, new advancements in highway materials technology have been developed which hold out the promise of significantly reducing highway construction costs, conserving valuable, yet dwindling, resources and continue to provide the high level of performance which the driving public demands and is entitled to.

One area where there is high potential for cost savings and resource conservation is in the recovery and reuse of by-product materials. One of the stipulations of RCRA is that government procurement agencies purchase items containing the highest practical percentage of recoverable or recyclable materials, consistent with product quality and price competition. One of the most promising areas for using recovered materials is in highway construction where large quantities of material are consumed and purchased by the government.

Although recycling of "waste" material for highway construction purposes has been practiced to some degree for many years, in general, the extent of such use has been far less than it could have been for the following reasons:

1. Uncertainties in quality and quantity of supplies.

2. Lack of producers or production facilities in certain areas.

3. Attitudes of state highway personnel which are essentially conservative, particularly where public funds are involved. Another characteristic of highway engineers is their general reluctance to aggressively investigate or readily accept new materials or concepts. It has often been stated that it takes as long as 20 years in order to evaluate fully, and accept routinely, the use of a new product in highway construction.

4. Lack of effective marketing, or overly aggressive and unprofessional sales approaches.

5. Politics, particularly the strong influence which comes from conventional material producers associations.

Today, however, because of declining fuel tax revenues and highway operating budgets, and the necessity to get more highway miles for the dollar, few, if any, public agencies can afford to perpetuate the overly conservative policies of the past. Reductions in highway funding ultimately translate into fewer highway construction projects for road building contractors. This not only results in unemployment and economic dislocation, but also threatens the economical survival of many large, well established construction businesses. In addition, the public demands that highways be maintained to a certain acceptable level of service.

It is, therefore, in the public interest for transportation agencies and policy makers at the Federal and state level to give much more serious consideration than they have in the past to increased utilization of recoverable and usable by-products for highway construction purposes. Not only does this alleviate to some extent the disposal problem associated with solid waste, but the introduction or substitution of recovered materials (such as fly ash) in certain highway construction products has been found in many instances to provide an improved product at a reduced cost. At the same time, use of such materials helps to conserve dwindling natural resources for uses in other applications where they are more urgently needed.

In evaluating the potential usefulness of various recoverable solid waste materials in highway construction, four criteria are applied to determine the reasonableness of using a specified by-product in a certain application. These criteria of reasonableness are:

1. Availability of supply.
2. Acceptable technical performance.
3. Comparable costs.
4. Minimum level of competition.

State and Federal highway engineers responsible for awarding construction contracts should be aware of the physical and chemical properties, as well as the potential applications, of usable by-products and the possible sources of such materials within their jurisdiction. If nothing else, useful recovered materials such as fly ash, should not be discriminated against in highway specifications and/or usage, simply because of lack of knowledge about the material or because of its differences with more familiar conventional construction materials.

Options such as provisions for receiving alternate bids or encouraging the use of value engineering in the award of construction contracts appear to be ways for stimulating increased utilization of by-product materials in highway construction. By carefully evaluating such recovered materials, and properly implementing their use, the possibility of substantial cost savings exist in many cases. Federal procurement guidelines need to be evaluated carefully for their potential in alleviating these problems.

PURPOSE OF GUIDELINES

The Resource Conservation and Recovery Act of 1976 as amended (RCRA), (PL94-580), Subtitle F, Section 6002(c), requires that procuring agencies of the Federal Government, and certain other entities receiving funds from the Federal Government, must procure items composed of the highest percentage of recovered materials practicable, consistent with maintaining a satisfactory level of competition. In addition, procuring agencies must undertake a review and revision of specifications to eliminate exclusion of recovered materials and require recovered materials to the maximum extent practical.

Section 6002(c) of the Act requires the Environmental Protection Agency to prepare, and from time to time revise, guidelines for use by procuring agencies in complying with the above requirements.

The intent of Congress as set forth in the Act is clear. The use of materials recovered from waste streams is to be stimulated by the Federal Government. One way of doing this is for the government to set an example in the purchase of products. However, the requiring of products which are composed of recovered materials, either entirely or partially, is a very complex task. In the case where the procuring agency has not had experience in purchasing such products, it means altering existing purchasing policies. For the agencies that have had experience in this area, it means insuring that their policies are consistent with the principles outlined in RCRA. This involves determining what constitutes recovered materials, and how to obtain the maximum amount of recovered materials usage consistent with acceptable business practices. Those practices must include procuring products that are available at a fair price; they must be readily available in terms of quantity and delivery times at all geographical locations; an acceptable number of bids must be received to insure competitiveness; and products must meet all performance criteria.

The EPA guidelines will serve several purposes. The basic usefulness will be that they are the vehicle through which a policy will be implemented. Thus, the basic attitude of the guidelines will be to stimulate the use of recovered materials. Ideally, this would occur through a "demand-pull" type of mechanism, where the demand for goods by the government will increase the marketability and availability of recovered materials. If the demand by the government is large enough, it will bring about a basic change in highway construction materials policies. This could lead to wider implementation of recovered material use in non-federally funded projects, such as state, county, city or other local government road building; and privately funded roads, parking lots, and other hard surfaced areas.

Another aspect of the guidelines is to increase the awareness of the potential applications of recovered materials. Although many procuring agencies have had experience in the use of recovered materials, some have not. The guidelines documents could stimulate those entities to study the use of recovered materials more carefully, and to become aware of the successful experience of other agencies in using those materials.

Perhaps the most important application of the guidelines will be to remove any unwarranted discrimination against recovered materials. They should be judged on technical and economic considerations only. There is evidence that in some areas recovered materials are not accepted on an equal footing with conventional materials in spite of a large body of technical data which suggest that they should be allowed to compete in the marketplace. The guidelines should aid in removal of those "institutional barriers."

Another purpose of the guidelines is more philosophical in nature. It is a proper function of government to bring about actions for the public good. RCRA was enacted as part of a natural resource policy. In that regard, the government must determine which natural resource policies are in the public good. In RCRA, Congress has stated its will by requiring the maximum use of recovered materials is a natural resource policy. A purpose of the guidelines is to reflect this national policy by laying out specific ways in which this policy may be implemented. Irrespective of how successful the guidelines are at this point in time in stimulating increased use of recovered materials, it is important that the government lay the framework for materials policies which are deemed to be in the nation's best interest for the long term.

Finally, an important purpose of the guidelines is to provide a blueprint for procuring agencies to implement RCRA. The guidelines must give specific instructions as to how agencies can procure highway construction products containing a maximum amount of recovered materials. Because each agency cannot (and should not) engage in a comprehensive analysis of the highway construction industry, the guidelines must contain information on the industry's ability to manufacture and supply products containing recovered materials, sources of supply, technical performance, and must highlight significant problems which a procuring agency may encounter in purchasing recycled products which are not encountered in purchasing other products.

In summary, the procurement guidelines will serve three purposes. The basic purpose is to enunciate government policy in natural resource conservation. The policy established by Congress is that use of recovered materials conserves natural resources. Another purpose of the guidelines is to implement the policy by providing a framework through which natural resources are conserved by stimulation of recycling. Finally, the guidelines serve as an information source for procuring agencies by providing detailed information on which agencies can base procurement decisions.

DEFINITION OF RECOVERED MATERIALS

RCRA uses the term "recovered materials" throughout the mandate to EPA. It is necessary that a specific definition of this term be set forth by EPA. The working definition being used by EPA is that "recovered material" is postconsumer waste and other secondary waste material and byproducts which have been collected or recovered from solid waste which has been disposed of or is destined for disposal. It includes fragments of products or finished products of a manufacturing process (including production of electricity) which has converted a raw material into a commodity of real economic value, but does not include those materials generated from and commonly reused within the original manufacturing process itself.

This definition has been further expanded by the development of four criteria to be used in the selection of recovered materials for which guidelines may be developed.

(1) The waste material must constitute a significant solid waste management problem due either to volume, degree of hazard or difficulties in disposal;

(2) Economic methods of separation and recovery must exist;

(3) The material must have technically proven uses;

(4) Federal purchasing power for the final product must be substantial.

In consideration of these criteria, four recoverable materials were selected for this study of highway construction materials:

(1) Fly ash from air pollution control at coal-burning power plants

(2) Kiln dusts from air pollution control at cement or lime plants

(3) rubber tires

(4) residue from municipal solid waste incinerators

At the present time, these materials most nearly fit the criteria set forth. However, materials such as sulfur from pollution control and recycled pavements as well as other materials may also become equally important. At such time as EPA determines that this is the case, they may develop guidelines to accommodate these materials.

ECONOMIC IMPACTS

Government Issues

Economic impacts on the government may occur as a result of government procurement of recycled products. These impacts could occur by either the government incurring additional administrative costs as a result of the procurement program or as a result of increased costs of products.

The costs of administration of the program could range from nearly zero to a large amount, depending on how the procurement guidelines are written. One agency--the General Services Administration (GSA) has had practical experience in administering a recovered materials policy in their purchases. The GSA experience has been that additional costs of their program in procurement specifications requiring recovered materials in products has been minimal. In actual fact, the recovered material specifications is one of a great number of specification items which must be checked and monitored by GSA. They report that any additional cost would be difficult to pinpoint, but in any case, the incremental cost of the recovered material specification is small.

On the other hand, if the procurement guidelines are written so as to require close monitoring on the part of the government, the expense could become quite large. This program might include training of groups of field inspectors to monitor and inspect manufacture and installation of construction materials. However, an accurate estimate can not be made without reference to specific requirements.

A possible economic impact on the government would be an increase in product prices. There is a price history followed by recovered materials as they develop into valuable products. In the beginning, the material is a waste which must be disposed of at some cost to the producer. At this stage, the material will be given away, or the producer will pay someone to utilize it as a product. As the status of the material changes from a waste to a usable by-product, the price increases, and the producer begins to charge for the material. The price is set by the free market system in accordance with supply and demand.

If the government programs are successful in developing new or increased markets for recovered materials, it will undoubtedly increase their price. If the government would mandate the use of these materials, the demand could exceed available supplies and costs could become quite high. On the other hand, if a free market supply and demand equilibrium is allowed to exist, the final products must compete in the marketplace with conventional products. In that case, the products containing recovered materials would rise no higher than the level set by market for conventional materials. Thus, even though the price of the recovered materials may increase, they will not increase indefinitely.

Under this set of free market conditions, there would be little or no additional cost to the government. The prices would be set by the normal forces of the marketplace and would not rise above the level for conventional materials. In fact, it could be argued that the entry of a new product in the market would increase competition, and possibly lower prices.

We conclude that the costs to the government depend on the way in which guidelines are written. If levels of recovered materials are mandated, a costly administrative system may be necessary, and artificially high prices may be caused by supply and demand imbalances. On the other hand, if a free market type of competition is allowed to occur with a minimum of monitoring and administration, the costs to the government would be insignificant.

Industry Issues

As in the cases previously discussed, adverse impacts could occur on some segments of the conventional highway materials industry if recovered materials are mandated. Under present guidelines, they might be forced to purchase equipment to allow use of recovered materials. New demand may cause the cost of the recovered materials to be quite high because of limited supplies. Some companies may not be able to manage the cash flow or capital investments required and could be put out of business. Others which are able to cope with the situation would simply pass their costs along to the consumer. On the other hand, if a more "free market" approach is used, a contractor in the normal course of events will incorporate recovered materials in his products as it becomes economical to do so.

Thus, the mandatory approach might cause some business failures and generally disrupt the industry, while an approach that maintains a competitive market would not be abnormally disruptive.

CERTIFICATION OF RECOVERED MATERIAL CONTENT

RCRA requires that vendors certify the level of recovered materials included in the products they supply. In the case of highway construction products, this is a relatively simple procedure. The products in question are readily identifiable, and can be quantified by standard testing procedures from product samples.

Highway construction products are purchased in accordance with quite detailed specifications as a matter of standard procedures. This includes material composition as well as performance criteria. Also, as a matter of course, the installation of highway material is monitored by engineers representing the procuring agencies, and tests are made on the installed materials.

A simple certification closure, such as contained in the Code of Federal Regulations, 41CFR Part 1-1, Subpart 1-1.2504 should be adequate. That clause states, "The offeror/contractor certifies that recovered materials will be used as required by specifications referenced in the solicitation/contract." The vendor in signing the bid document is then agreeing to meet the material specifications, and no separate certification should be needed.

The percentage of recovered material used should normally be certified on a per project basis, as opposed to certification of the average amount to be used over the course of a year, for instance. Within technical performance limits, a procuring agency may allow the percentage to be certified within a small range, rather than requiring an exact percentage. The purpose of this flexibility is to not discourage potential suppliers who may be fearful that if an exact percentage is certified for a government contract, only that exact percentage may be supplied. Weather conditions or material variations, for example, may require modification of the material design.

SPECIFICATIONS

The specific impact of the guidelines will be in the writing of specifications. Highway construction products are specified in detail, and these specifications spell out material composition. Section 6002 of RCRA requires revision of all specifications for which Federal agencies have drafting and review responsibility so that they no longer exclude the use of recovered materials--and so that they incorporate the use of recovered materials to the maximum extent. In our review of conditions in selected states, there was no evidence that any specifications exist which exclude recovered materials. Rather, they specify what will be included. That will be where the guidelines should focus.

To assist agencies in achieving compliance with this requirement, alternatives may be suggested to an otherwise strict interpretation of Section 6002. There are three major categories of specifications for which recommendations could be made:

- Guide specifications--typically, model standards or specifications issued by a procuring agency or other independent agency such as AASHTO or ASTM, which are suggested or required for use in the design of all of the construction projects of an agency (these are often referred to as design standards of design guidelines).
- Contract specifications--a precise set of specifications prepared for a particular construction project, which contains such items as design, performance, and material requirements for that project.

- Material specification--a specification that stipulates the use of certain materials to meet the necessary performance requirements.

Guide Specifications

Procuring agencies will need to review and revise guide specifications to comply with the recommendations of guidelines. In doing this, the agencies will need to eliminate any discrimination, either direct or indirect, against the use of recovered materials. In addition they must ensure that guide specifications require that the use of recovered materials be considered and incorporated, where appropriate, into contract specifications for individual construction projects.

Contract Specifications

Ultimately the guideline will have its greatest effect on contract specifications which are prepared for each individual construction project. Agencies should make sure that specifications for individual construction contracts allow for the use of recovered materials as an alternate material, unless it can be shown that this would be technically inappropriate. The agency should document decisions to exclude recovered materials from contract specifications, in order to respond to possible protests or inquiries. Placing the burden upon the procuring agency to assure that recovered materials are allowed in contract specifications is particularly important where the design function is outside this agency, where construction projects are being performed as a result of grants, loans, funds, etc. Thus, it is critical that the technical officer or engineer on a contract work closely with the contracting or grant officer to assure that recovered materials are appropriately considered.

Material Specifications

In many cases there already exist guide specifications, and many states have their own specifications which specify use of recovered materials in specific instances. These specifications have been tailored to fit technical performance criteria for the conditions found in each locality. They take into account such variables as the local availability (and common use) of different types of asphalt cement, aggregates, and recovered materials; and soil conditions, weather, local construction practices, and other factors which affect product performance. It is imperative that these locally derived material specifications be utilized where feasible in order to insure the successful use of recovered materials. In addition, where specifications for recovered materials do not presently exist, it is imperative that they be developed in light of local conditions so that they will be technically sound.

Development of Specifications

Material specifications can generally be considered to be developed at the state level. Although states may use guide specifications, the local factors previously mentioned can be incorporated at the state level. Local governments and private entities tend to use state specifications, or to modify them slightly for their own use.

Every state has its own way of constructing specifications, but many follow a similar sequence. The first step is that a new product is brought to the attention of an "expert" in a material area of a state transportation department. This new material is then evaluated through literature searches, contact with the FHWA and with other states that have used or considered use of the material, and through laboratory experiments performed within the state.

The next step is to lay test strips, usually in cooperation with a product manufacturer. Then begins a long period of evaluation of the product. It is not uncommon for a highway agency to require 5 to 20 years for complete evaluation of a product. However, when a critical need is perceived, highway agencies can accelerate this evaluation period substantially.

After successful experience has occurred, a specification is written. This may take place as soon as one or two years of apparently successful field performance has been observed. Typically, a panel is convened, and users and producers of the material work with state engineers to agree on a technically acceptable specification.

In order for an acceptable specification to be written, this sequence of events is necessary. EPA should not, and probably could not, circumvent, or even speed up, any of these events. However, some states which do not presently have specifications are at an advanced stage of the process, and could produce specifications in a short period of time. The maximum impact of the guidelines is to insure that the specifications process stays on track, and proceeds with reasonable speed.

GUIDELINE OPTIONS

General Comments

Included in the remainder of this report is a discussion of specific guideline options. After consultation with representatives of the Federal government, state agencies, private contractors, material suppliers, product manufacturers, local governments, and other interested parties, a set of possible guideline options were developed. These include the following:

1. Dual bids and optional bids
2. Dual bids and optional bids applicable to selected states
3. Increase and improve educational activities
4. Grants, bonuses, and other financial incentives
5. Phased in, or delay of guideline implementation

These five options are discussed in Chapters 5, 6, 7, and 8 in terms of issues specific to the various recovered material products. The advantages and disadvantages of each option are discussed.

In addition, two other options will be discussed here because the discussion applies equally to all of the materials. Those options are no guidelines, and mandatory guidelines.

No Guidelines

One alternative available to EPA is to decline to issue any guideline for a given recovered material. This should be done only after a careful analysis reveals that the recovered material does not at present or will not in the near future: 1) constitute a significant solid waste management problem due to either volume, degree of hazard, or difficulties in disposal; 2) have readily available economic means of recovering the material and manufacturing a product which can be sold at a competitive price; 3) have technically proven uses; or 4) result in products for which Federal purchasing power is substantial.

From the preceding discussions, and also in subsequent analyses in this report, it is clear that the recovered materials chosen for this study all meet the criteria stated, and that guidelines should be issued. However, in some cases EPA may decide that a guideline at this time is premature because any one of the four criteria may not be fulfilled to a satisfactory degree. EPA could therefore postpone a guideline for several materials until re-examination at some point in the near future indicates that all of the criteria are adequately fulfilled.

Mandatory Guidelines

Another possible guideline would be to require a fixed minimum level of recovered material in all products purchased by the Federal government, or that some class of products could only be purchased if made from recovered materials. For example, a guideline could require that whenever a stabilized base is required that only lime-fly ash-aggregate could be used. Another possible example would be that asphalt concrete would have to always utilize at least 50 percent incinerator residue in the aggregate fraction.

Any such mandate would cause serious problems, and undoubtedly would result in frequent bidding situations with no bids being received. Many of the recovered material products studied are not available in all locations, so could not be obtained locally. In addition, the availability may fluctuate greatly from time to time. Also, the wide variation in soil conditions, climate, aggregate composition, and other variations across this country mean that products must be tailored to individual locations. Local officials must have the option of selecting products that will perform satisfactorily.

The one suggestion made to literally hundreds of people contacted in the course of this study that received an unanimous negative response was the suggestion that EPA could decide on a mandatory guideline. Virtually everyone connected with the highway construction industry felt that such a guideline would ultimately result in less recovered material being used. Even marketers of recovered material products objected. Their feeling was that a mandatory requirement would force use of their product in inappropriate applications, thus leading to possible failure and a bad reputation for their product.

Virtually everyone favored an approach more closely aligned with the competitive marketplace. Thus, a mandatory guideline approach would meet with resistance from all quarters. It appears that in the long run, this approach would be counter productive, and would not even increase the use of recovered materials. Therefore, it would seem that a mandatory guideline would be inappropriate.

Chapter 4

VIEWPOINTS OF GOVERNMENT AGENCIES AND MATERIAL SUPPLIERS

INTRODUCTION

One of the critical issues in the development of a recovered materials market is the acceptance of those materials by highway construction decision makers. Many factors are involved in the making of material decisions, which include not only technical issues which can be decided in laboratories and by the construction and evaluation of test strips, but also in the attitudes of the decision makers, and in the complex personal and professional ramifications of major materials decisions.

As a part of this study, a number of personal interviews were conducted to learn more about the intangible, or institutional issues that affect decisions. This chapter is a summary of those findings.

STATE AGENCIES

The state departments of transportation are the usual focus of activity in decision making for materials use. There are many reasons for this. One important factor is that there is significant variation geographically in virtually every aspect affecting materials decisions. These include specific types of asphalt cement available which depends on refinery practice and types of crude oils used, composition and quality of aggregates, composition and quality of recovered materials, availability and quality of lime, soil types on which highways are constructed, climate, local construction practices, and costs. This makes centralized (Federal) decision making very cumbersome and leads to decentralization.

Another important reason for the states being a center of activity is the historical political relationship in this country between the Federal government and the states. Much of the highway construction funds spent in this country come from Federal sources. These are predominantly administered through state departments of transportation, which is a logical level of decentralization of administration.

Thus, the materials decisions must be decentralized for reasons of technical complexity, but the evaluation of materials and writing of specifications is a lengthy, complex, and costly process. This generally precludes carrying out those activities at the county or local level. It is only at the state level that research laboratories can be maintained, and staffs of experts in various fields can be retained. Thus, the state is the logical level at which detailed materials decisions are made.

Many of the people interviewed in the course of this project described highway construction agencies and related industries as the "most conservative" in the country. While this may be an exaggeration, it is clear that acceptance of change of any kind comes very slowly by many standards. But, it is important to understand that this conservative attitude has a rational basis.

The reader should try to imagine the importance to an individual of basic decisions affecting road construction. Some roads cost in excess of 10 million dollars per mile. While most cost less than this, any road construction project involves quite large sums of money. It is also important to realize that the decision maker in a state DOT is a publicly visible person. He has typically worked for decades to establish his expertise and has a very high professional reputation. Consider also that the private automobile is a key part of the American way of life, and everyone drives on the streets and roads.

Putting all of this together, imagine a new roadway which begins to deteriorate rapidly, causing an unsatisfactory riding experience. The public officials are vulnerable to public ridicule for a new road which does not perform properly. Even if there is an appearance (true or not) that massive sums of money have been misused, the official may be subject to disciplinary action or transfer. In that event, his personal and professional reputation may be tarnished.

This possible sequence of events is not recounted here as an accurate description of what happens typically, but what a public official must bear in mind as materials decisions are made. There is little margin for error in materials decisions. If a mistake is made, the downside risk may be very serious. If a change in materials is made and it is not a mistake, the upside benefits for the public official are marginal. This is a factor that contributes to very slow change in the highway construction industry.

Another contributing factor to the slowness in change in materials decisions is the lack of adequate knowledge and procedures to test mateirals in a laboratory. Test strips must be constructed, and then must be evaluated. It may be many years before the results are final although results can be obtained in three to five years if a priority is assigned to the project. Typically, when a new material is used, early test strips fail. Procedures must then be altered, and new test strips put down. After these techniques are refined, the strips may have to remain in place for many years in order to tell if they outperform conventional materials.

As a result of these factors, state agencies have very firm views that their materials decisions must be solidly based in sound engineering studies. Thus, above all else, the materials must perform in an acceptable manner. There is concern among many state agencies that EPA guidelines might result in pressure to use recovered materials whether those materials are best suited to their applications or not. They cite the lack of national uniformity in administration of Federal directives, where a local or regional officer may be overzealous in application of guidelines. In fact, all fifty states surveyed by the American Association of State Highway Transportation Officials (AASHTO) voiced some opposition to guidelines.

Also underlying the interviews with state agencies was the feeling of resentment at the number of Federal restrictions already in place. A point of view taken by some is that Federal tax money is taken from the state, and only a portion is returned. Some feel that the money should be returned without "strings" attached. They feel that only people close to the scene know how best to spend the money wisely, and that Federal monitoring leads to waste and inefficiency. Several state officials went so far as to say that they would actively work to circumvent any guideline as a matter of principle. Thus, guidelines to encourage recovered materials would be counter productive in these instances. On the other hand, some state officials said they would not mind guidelines as long as they did not mandate specific levels of recovered materials be used.

In summary, it was found that state agencies held the key to materials decisions. These agencies are quite conservative in their approach. There generally is a long and detailed set of steps which a new material must follow before it is accepted as a standard material. This lengthy evolution process has as its goal to provide highways which are soundly engineered, and which will provide good quality.

It was also found that generally state agencies resent Federal restrictions and guidelines. It is the opinion of most state officials interviewed that EPA guidelines would not be effective in increasing the use of recovered materials. This is because they are already using recovered materials or evaluating their use. However, it was the observation of the research team, that in states where a high level public official strongly supports the use of recovered materials, the process of implementation can be accelerated. But, there is no evidence that guidelines will in any way enhance those possibilities, although they may be used as a tool by such an individual.

FEDERAL AGENCIES

Direct Federal Programs

The source of most money available for highway construction is from the Federal treasury. Whereas most of the funds are made available to state and local governments on a shared cost basis, the Federal government funds a small amount of road construction directly. These include roads on military property, in national parks and forests, Indian reservations, and other Federally owned property. The Federal Aviation Administration also funds airport runway and taxiway construction.

In the case of the military, they have their own research laboratories and write their own specifications. However, final decisions rest with base commanders. Although military performance standards must be met, the use of state specifications in the state where the construction takes place is common.

The direct Federal decision makers share the states' concerns that the road construction function must always result in wise use of tax dollars, in that the paramount concern is a road that performs well and costs a fair price. They are particularly concerned that if levels of recovered materials are mandated, they may not be able to make the best decisions in regard to road construction.

Another problem incurred in direct Federal procurement is the remote location of many of the road construction projects. Most of the recovered materials are generated close to population centers. Thus, for many direct Federal projects there may be recovered material supply problems. Thus, guidelines would have to have optional features of some fashion in order to allow for an orderly procurement process.

Indirect Federal Programs

By far the dominant highway construction activity program in the U.S. is the Federal aid program administered by the Federal Highway Administration (FHWA). This results in cost sharing by the Federal government and other public agencies in road building costs. This ranges from major U.S. highways, such as the interstate program, where the Federal cost share is 90 percent and the state share is 10 percent, to roads of lower Federal-aid classification, in particular where the Federal role is only 50 percent, and state and local governments pay 50 percent of the costs.

In this study, FHWA was identified as the primary procurement agency for which EPA guidelines would be written. They administer and monitor all Federal aid projects, and routinely require that certain procurement standards are met.

In regards to their relations with the states, the policy of FHWA is to allow as much freedom as possible in the procurement process. The states basically write the specifications for the road construction projects, including material selection. The states choose the contractors, and provide the on-site project monitoring. However, approval is required from FHWA, and FHWA standards must be met.

FHWA also funds a substantial amount of research and development of highway construction products. This includes laboratory research and field testing. Frequently, field work is carried out in cooperation with states. FHWA has provided leadership in the use of recovered materials by directing research efforts in their use. They have funded laboratory research and field tests to develop mix designs and to develop knowledge of how to properly prepare and apply the recovered materials. In addition, they have provided implementation packets that include slide shows and other instructional materials that can be used for training and informing state DOT personnel in the design and use of recovered materials. Also, regional FHWA engineers have been instructed to help states in finding ways to use recovered materials.

Thus, it appears that FHWA has had a generally positive attitude towards the use of recovered materials, and have acted to increase their use. However, FHWA is made up of many individuals, and there is not universal enthusiasm for use of recovered materials by every individual in FHWA. This may be particularly true at the regional level, as at least one state has reported that attempts to use recovered materials have been thwarted by the overzealous requirements placed on recovered material use by FHA division engineers, although, if a state is committed to use of a material, the decision can be appealed. However, FHWA resistance appears to be the exception, as most states reported that FHWA has generally been cooperative, or helpful in their proposals to use recovered materials.

Pershaps an important aspect of the federal-state relationship was revealed by the interviews. FHWA at the national level seems anxious to not impose undue restrictions on state procurement. However, state DOT officials say they are reluctant to take leadership in use of new materials because they can primarily use only materials approved by FHWA. Thus, both entities report looking to the other for leadership in recovered material use. Perhaps the apparently tentative position taken by both sides is related to the conservative nature of the highway construction industry. It takes many years for anyone to develop enthusiasm for a new material product, because if it does fail, the downside consequences turn out to be quite severe.

MATERIAL SUPPLIERS

Recovered Material Suppliers

The suppliers of recovered materials could potentially make significant monetary gains if procurement guidelines are successful in stimulating markets. However, all of the people representing the recovered materials producers voiced opposition to mandatory guidelines. They fear that such guidelines could force use of their material in such a manner that application could be done incorrectly and cause their product to fail. Also, mandatory guidelines could lead to use of their material in inappropriate applications, also causing failure and subsequently harming their reputation. Another disadvantage of mandatory guidelines would perhaps be an increase in demand which would be more rapid than orderly growth would allow. This could lead to short supplies, construction delays, and use of low quality materials, all of which could be a future deterrent to use of recovered materials.

What the recovered material suppliers want is a fair test for their products. They cite the near impossibility of obtaining test strip conditions to give their product a chance in the marketplace, even if they would donate the materials and assist in the construction.

What they want the most is that their material have a chance to compete in the marketplace. They feel that if a contractor wants to bid a recovered material, and it would perform in an acceptable fashion, it should be allowed to compete. However, the real problem is on agreeing when it will perform in an acceptable fashion.

Conventional Material Suppliers

The conventional material suppliers could experience substantial reductions in demand for their material in some locations, because recovered materials can be substituted for their products. A reaction to this by some producers is to resort to persuasion or political pressure to try to block acceptance of recovered materials. Another approach is to attempt to influence the writing of specifications so as to unduly increase the installed cost of recovered materials.

On the other hand, some producers have taken another approach. They view recovered materials as another business venture. Thus, instead of fighting recovered materials, they expand into that business. This puts them in an extremely good situation, as they can supply both kinds of products to any given construction job.

Thus, the range in attitudes by the material suppliers can run the whole gamut from very supportive to very combative.

Chapter 5

USE OF POWER PLANT ASH IN HIGHWAY CONSTRUCTION PRODUCTS

INTRODUCTION

There is presently a move to more reliance on coal as a fuel for electricity generation in the U.S. At the same time, pollution controls are becoming more and more stringent. These two effects together have given rise to a rapidly growing solid waste problem because of the residuals which result from coal combustion. The residual materials collected from the burning of coal at electric utility plants are referred to as power plant ash. These materials are produced in two forms: fly ash and bottom ash. Fly ash is the fine-grained dusty material from the combustion of ground or powdered coal that is recovered from boiler flue gases by means of electrostatic or mechanical collection systems. Bottom ash is the granular material or the boiler slag which, after coal combustion, collects in the ash hopper at the base of the boiler unit.

In 1970, 39 million tons of power plant ash were produced, but by 1979 this value had grown to over 75 million tons annually. This makes power plant ash one of the largest solid waste disposal problems in the U.S. This problem is ameliorated to some extent by use of fly ash, primarily as a cement replacement in concrete and in the manufacture of portland cement. But, generally less than 12 percent of the waste is used. In this chapter, opportunities to use significant quantities of power plant wastes in highway construction products is discussed. Inclusion of fly ash in portland cement is excluded from this discussion because it has been the subject of a previous study for EPA.

DESCRIPTION OF POWER PLANT ASH GENERATION AND RECOVERY

Flue gases from coal combustion are customarily collected and routed to electrostatic precipitators and/or baghouse particulate collection devices. In this way, the airborne solid residues are filtered from the combustion stream. In addition, some unburned residues fall to the bottom of the combustion chamber and are removed as bottom ash.

Fly Ash

There are three basic types of coal-burning boilers: stoker-fired, cyclone-fired, and pulverized coal-fired units. Stoker-fired units generally produce a comparatively coarse fly ash, the amount varying depending on whether the stoker is a traveling grate or spreader type. With cyclone or slagging boilers, a smaller portion (from 0 to 65 percent) of the fly ash is released into the flue gases and collected. Most of the fly ash produced in cyclone units melts and is collected with the bottom ash as a slag at the base of the furnace. In pulverized coal-fired units, finely ground coal is burned in suspension, causing the fly ash to enter the stream of flue gases for eventual removal either by mechanical collectors or electrostatic precipitators.

After collection, the characteristics of fly ash are further influenced by the techniques used at the power plant for ash handling and storage. To some extent, ash handling and storage techniques are related to power plant design, but are also influenced by utility practice and available land. Basically, ash handling and storage is accomplished either by wet or dry methods. Approximately 67 percent of all ash currently produced is handled dry. Dry methods involve short-term storage of fresh ash in hoppers or long-term storage of the dry ash in silos. Dry fly ash can be discharged through gates or pneumatically into transport vehicles.

Wet handling of fly ash involves adding a certain quantity of water to the fly ash and disposing of it either in a conditioned or ponded form. Conditioned fly ash results from the addition of small amounts of water (30 percent or less by weight) sufficient to prevent dusting of the fly ash and enable it to be stockpiled in large quantities. Ponded fly ash results from the addition of large amounts of water to produce a slurry and enables transport of the ash by pipeline to settling ponds or lagoons. At many power plants, fly ash and bottom ash are collected and disposed of together in the same lagoon, although a power plant may employ more than one means of ash collection and storage.

Not only are there differences in the fly ash from different coal sources and power plants, but there is also a certain amount of variability in the ash from a single power plant. Normally, fly ash is gray in color, although the color can range from cream to light tan, through various shades of gray, to dark brown, and nearly black. The cream color is usually indicative of high calcium oxide content. The tan color is usually attributed to the presence of iron oxide, while the darker colors are most often associated with an increasing presence of carbon.

Fly ash is composed of fine particles that are predominantly spherical in shape, solid or hollow, and of a glassy or amorphous nature. The carbon content in fly ash is composed of angular particles. The particle size distribution of most bituminous coal fly ashes lies essentially within the range of a silt. Particle sizes for glassy spheres in bituminous coal fly ash vary from 10 to 300 microns. In general, lignite and sub-bituminous coal fly ashes are coarser than bituminous coal fly ashes.

Bottom Ash

Approximately 25 to 30 percent of all ash produced annually is bottom ash. Basically, two different types of bottom ash are produced: dry bottom ash and wet bottom boiler slag. The term "power plant aggregate" is sometimes used to include both forms of bottom ash.

Dry bottom ash is produced by injecting pulverized coal into the furnace and burning the coal over open grates. This type of boiler is referred to as a "dry bottom" boiler. The ash that is not fine enough to go up the stack with the boiler gases in the form of fly ash instead solidifies and agglomerates into coarse particles (from 5 cm down to 75 mm). Some of the larger pieces may be porous particles with varying degrees of friability. These coarse particles then fall into the ash hopper at the bottom of the furnace.

The term "dry" bottom ash refers to the solid state of the ash as it drops into the hopper. A certain amount of molten slag which forms on the internal surface of the boiler also drops into the ash hopper. In a typical dry bottom coal-fired furnace, from 20 to 30 percent of the ash is bottom ash. The ash hopper also generally contains some water. When a sufficient amount of bottom ash drops into the hopper, it is removed by means of high pressure water jets and conveyed by sluiceways to a coarse crusher and on to a storage area.

The other basic boiler type is referred to as a "wet bottom" or "slag tap" boiler. In this type of boiler, the bottom ash is kept in a molten state and tapped off as a liquid. There are two varities of "slag tap" boilers: those that burn pulverized coals and those that burn crushed coals. Boilers burning crushed coals are known as cyclone boilers. Both boiler types have a solid base with an orifice that can be opened to permit the molten ash that has collected on the base to flow into the ash hopper below. As is the case in dry bottom furnaces, the ash hopper in wet bottom furnaces also contains quenching water. However, when the molten slag comes in contact with the quenching water, it fractures instantly, crystallizes, and forms a black angular, glassy material.

The term "wet bottom boiler slag" describes the molten state of the slag as it is drawn from the furnace. In a typical wet bottom furnace, 50 to 70 percent of the ash produced will be boiler slag, with the remainder being fly ash. In cyclone furnaces, production of ash is more like 80 percent boiler slag and 20 percent fly ash. Wet bottom boiler slag is sometimes also referred to as "black beauty" because of its black, glass-like appearance. At intervals, high pressure jets wash the slag from the hopper pit into a sluiceway in which it is conveyed to a collection basin for dewatering, possible crushing, and disposal or reuse.

Dry bottom ashes have angular particles with a very porous surface. Some glassy particles can also be seen, particularly in the smaller sizes. These glassy particles represent the molten slag from the internal surface of the boiler. Bottom ash particles range in size from fine gravel to fine sand. It should be noted that some variation in particle size distribution can be expected from bottom ash samples taken from the same plant source at different times.

In contrast to dry bottom ash, boiler slag is predominantly single-sized in the range of 0.5 to 5.0 mm. The particles themselves are hard, usually black (sometimes dark brown) in color, and glassy with a smooth surface texture like crushed glass. However, if gases are trapped in the slag as it is tapped from the furnace, the quenched material will be somewhat vesicular or porous. Some vesicularility may be beneficial, in that it improves the surface texture.

QUANTITIES OF RECOVERED MATERIALS

National Generation

The relative amounts of fly ash and bottom ash produced at a particular power plant location are determined mainly by the design of the boiler units. However, as a general rule, 70 percent or more of all power plant ash is fly ash.

The production of ash has increased tremendously over the past fifteen years as more coal-burning power plants come on line and ash collection methods improve. Ash collection and utilization statistics compiled by the National Ash Association show that fly ash production has tripled between 1966, the first year the Association began collecting data, and 1979. In 1966, 17.1 million tons of fly ash was collected, while in 1979, the most recent year that statistics are available, a total of 57.5 million tons of fly ash was collected, along with an estimated 17.7 million tons of dry bottom ash and boiler slag (Table 5-1).

Geographical Generation Patterns

In 1979, ash was produced at a total of 380 coal-burning power plants located in 39 states. However, the largest quantities of ash are generated in the Appalachian region east of the Mississippi River. The locations of all existing coal-fired power plants in the United States are shown in Figure 5-1. The approximate quantities of fly ash and bottom ash presently being produced by major electric utilities in each state are shown in Table 5-2 and Figure 5-2. Bottom ash is estimated from the fly ash numbers by assuming that bottom ash production is 30 percent of the fly ash generated. These quantities were computed based on 1978 consumption of coal by electric utility companies in each state, as shown in Table 5-2. From Table 5-2 and Figure 5-2, it is evident that half of all the ash which is now being generated in the United States is found in the six largest ash-producing states (Ohio, Pennsylvania, Illinois, Indiana, Kentucky, and West Virginia).

Table 5-1

PRODUCTION OF POWER PLANT ASH IN THE UNITED STATES SINCE 1970
(Millions of Tons)

Year	Fly Ash	Dry Bottom Ash	Boiler Slag	Total Ash
1970	26.5	9.9	2.8	39.2
1971	27.8	10.1	5.0	42.9
1972	31.8	10.7	3.8	46.3
1973	34.6	10.8	3.9	49.3
1974	40.4	14.3	4.8	59.5
1975	42.3	13.1	4.6	60.0
1976	42.8	14.3	4.8	61.9
1977	48.5	14.1	5.2	67.8
1978	48.3	14.7	5.1	68.1
1979	57.5	12.5	5.2	75.2

Note: In 1978, a total of 8.4 million tons of fly ash was utilized, representing 17.4 percent of the 48.3 million tons of fly ash produced. This is the highest percentage of ash utilization in any one year so far. Replacement of portland cement in concrete mixes is the largest single use of fly ash.

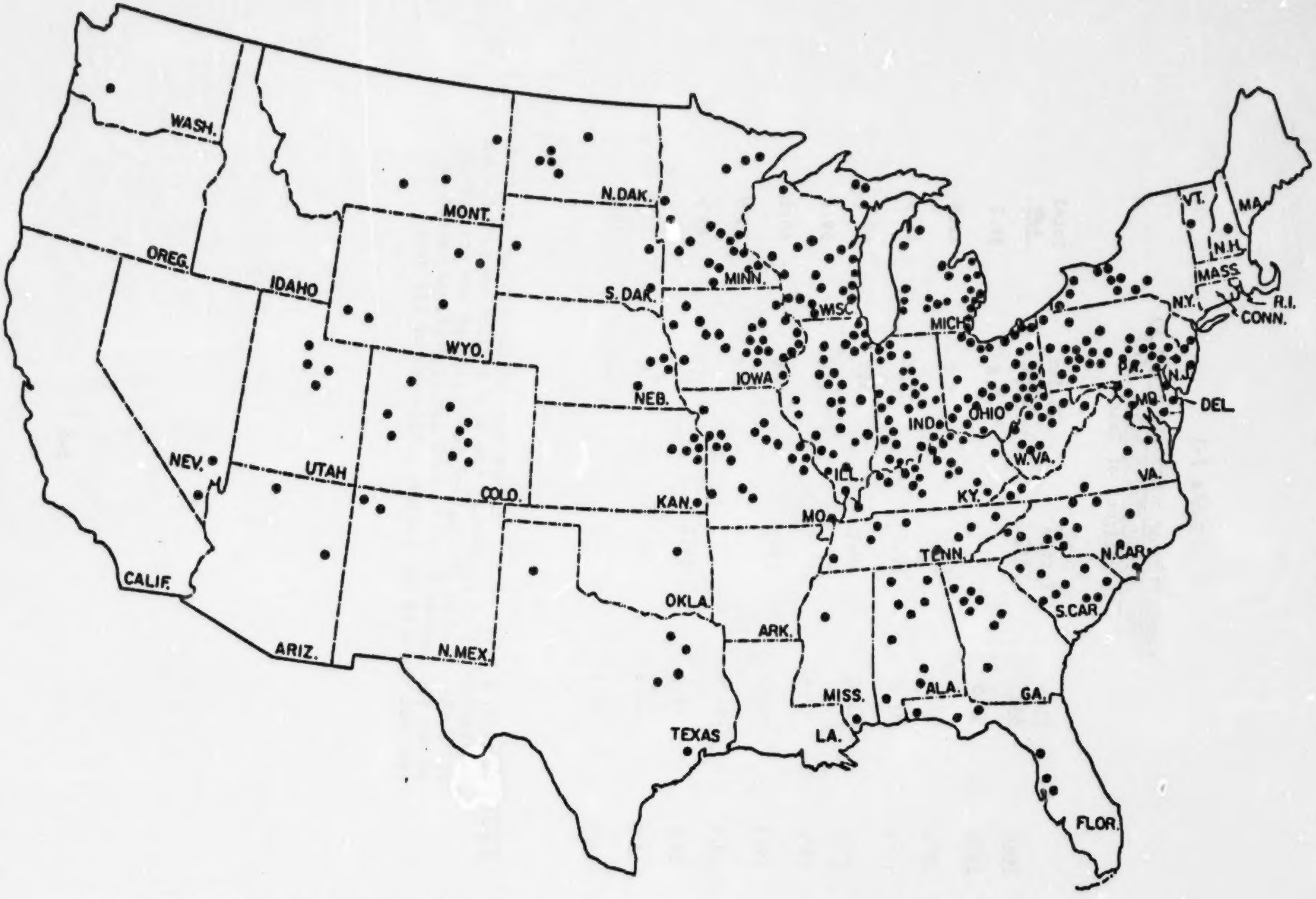
WASH.
OREG.
CALIF.
NEV.
IDAHO
MONT.
WYO.
UTAH
ARIZ.
COLO.
N.MEX.
N.DAK.
S.DAK.
NEB.
KAN.
OKLA.
TEXAS
MINN.
IOWA
MO.
ARK.
LA.
WISC.
ILL.
MISS.
MICH.
IND.
KY.
TENN.
ALA.
OHIO
W.VA.
GA.
FLOR.
S.CAR.
N.CAR.
VA.
MD.
DEL.
PA.
N.J.
N.Y.
CONN.
R.I.
MASS.
N.H.
VT.
MA.

Figure 5-1. Location of power plant ash.

Table 5-2

QUANTITIES OF UTILITY COAL BURNED AND FLY ASH/BOTTOM ASH PRODUCED IN 1978 BY STATE

(Thousands of tons)

	Number of Plants	Utility Coal Burned	Total Ash Produced
EPA Region 1			
Maine	-	-	-
New Hampshire	1	750	117
Vermont	1	10	1
Massachusetts	-	-	-
Connecticut	-	-	-
Rhode Island	-	-	-
Total	2	760	118
EPA Region 2			
New York	10	6,350	991
New Jersey	4	2,220	346
Total	14	8,570	1,337
EPA Region 3			
Pennsylvania	27	40,340	6,293
Maryland	5	4,230	660
West Virginia	12	27,740	4,328
Virginia	6	4,830	754
Dist. of Columbia	-	-	-
Delaware	2	1,170	182
Total	52	78,310	12,217
EPA Region 4			
Kentucky	19	26,880	4,194
Tennessee	8	21,700	3,385
North Carolina	13	21,690	3,384
South Carolina	9	6,860	1,070
Mississippi	2	1,450	226
Alabama	9	17,100	2,668
Georgia	8	15,620	2,436
Florida	6	8,630	1,347
Total	74	119,930	18,710
EPA Region 5			
Minnesota	18	12,400	1,934
Wisconsin	18	11,310	1,764
Michigan	24	25,190	3,930
Illinois	27	35,780	5,582
Indiana	26	29,280	4,568
Ohio	32	53,310	8,316
Total	145	167,270	26,094

Note: Total ash quantities determined by assuming approximately 15 percent ash content for all utility coal burned.

Table 5-2 (continued)

QUANTITIES OF UTILITY COAL BURNED AND FLY ASH/BOTTOM ASH PRODUCED IN 1978 BY STATE

(Thousands of tons)

	Number of Plants	Utility Coal Burned	Total Ash Produced
EPA Region 6			
Texas	6	9,780	1,526
New Mexico	2	8,820	1,375
Oklahoma	1	600	94
Arkansas	-	-	-
Louisiana	-	-	-
Total	9	19,200	2,995
EPA Region 7			
Kansas	6	6,350	991
Missouri	18	21,750	3,393
Iowa	22	6,730	1,050
Nebraska	4	2,220	346
Total	50	37,050	5,780
EPA Region 8			
Montana	3	1,720	268
North Dakota	5	8,020	1,251
South Dakota	3	2,360	368
Wyoming	5	11,380	1,776
Utah	4	2,490	389
Colorado	9	5,680	887
Total	29	31,650	4,939
EPA Region 9			
California	-	-	-
Nevada	2	5,140	802
Arizona	2	7,560	1,179
Total	4	12,700	1,981
EPA Region 10			
Washington	1	5,410	844
Oregon	-	-	-
Idaho	-	-	-
Total	1	5,410	844
U.S. Total	380	480,850	75,015

Note: Fly ash quantities determined by assuming approximately 15 percent ash content for all utility coal burned.

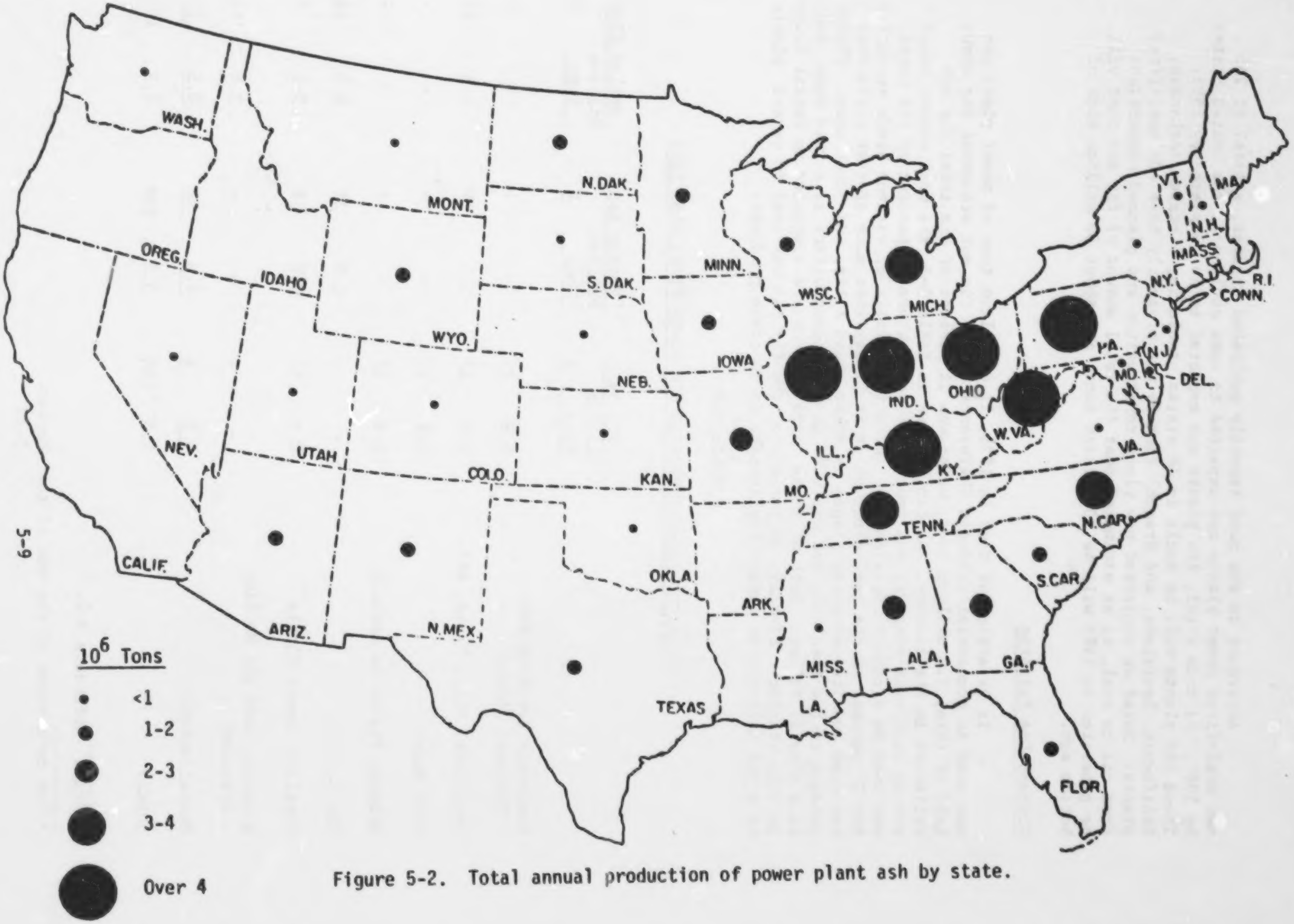
WASH.
OREG.
CALIF.
NEV.
IDAHO
MONT.
WYO.
UTAH
ARIZ.
COLO.
N.MEX.
N.DAK.
S.DAK.
NEB.
KAN.
OKLA.
TEXAS
MINN.
IOWA
MO.
ARK.
LA.
WISC.
ILL.
MICH.
IND.
OHIO
KY.
TENN.
MISS.
ALA.
GA.
FLOR.
S.CAR.
N.CAR.
VA.
W.VA.
PA.
MD.
DEL.
N.J.
N.Y.
CONN.
R.I.
MASS.
VT.
N.H.
MA.
10⁶ Tons
<1
1-2
2-3
3-4
Over 4

Figure 5-2. Total annual production of power plant ash by state.

According to the most recently published figures, a total of 255 new coal-fired power plants are expected to come on line in the United States by 1987. Of this total, 164 plants are expected to be completed by 1985. These 164 plants will be built in 36 states, including 4 states (Arkansas, California, Louisiana, and Oregon) that do not presently have any coal-fired plants. Based on projected new plant construction and planned conversions from oil to coal, it is estimated that the total amount of fly ash that will be generated in 1985 will be 90 million tons, and about 30 million tons of bottom ash.

Current Use Patterns

It is estimated that in 1978, 11.4 million tons of power plant ash was used in commercial products (Reference 5-1).* Fly ash accounted for about half of this, 5.3 million tons, which was 11 percent of the total fly ash collected in the country. As can be seen in Table 5-3, the most common usage was in ready-mix concrete and concrete blocks, where 35 percent of the total was used as a cement replacement. Structural fills of various kinds accounted for 17 percent of the use, although it is likely that much of that application was used on-site at power plants as dikes, road fills, and other uses. Thirty percent of the total fly ash was used in road construction as a road base, and as a mineral filler. Both of those applications are discussed in detail later in this chapter. Finally, 12 percent of the fly ash was used in cement plants as a raw material or cement replacement in concrete products.

Table 5-3

ESTIMATED END-USE PROFILE FOR POWER PLANT ASH, 1978

	Fly Ash		Bottom Ash		Boiler Slag	
	Million Tons	%	Million Tons	%	Million Tons	%
Ready-mix Concrete and Concrete Blocks	1.9	35	-	-	-	-
Structural Fill, Dikes, etc.	0.9	17	1.2	38	0.4	13
Road Base	0.8	15	-	-	-	-
Mineral Filler in Asphalt	0.8	15	-	-	-	-
Ice Control	-	-	1.2	39	0.5	16
Portland Cement Plants	0.6	12	0.2	5	0.1	3
Blasting Sand and Roofing Granules	-	-	-	-	1.4	48
Miscellaneous	0.3	6	0.6	18	0.5	20
Totals	5.3	100	3.2	100	2.9	100

Source: Reference 5-1.

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* See references at the end of the chapter.

The estimated use of bottom ash in commercial products was 3.2 million tons--22 percent of the dry bottom ash collected in 1987. Fifty-seven percent of the boiler slag collected, or 2.9 million tons were also used for commercial products. In Table 5-3, it can be seen that bottom ash was used primarily for structural fills and ice control, while boiler slag was used for blasting sand and roofing granules.

In most of these applications, power plant ash is used as an inexpensive substitute for other materials, usually a mineral of some sort. For example, its use as a structural fill is predicated on obtaining ash cheaper than earth. This occurs only if it can be used at the power plant, or perhaps within five to ten miles of the plant so that transportation is minimized. In applications such as these, the composition of the ash is not important so that quality control in terms of chemical composition and physical condition is not crucial. However, because of the stringent transport restrictions dictated by the economics of use, there is not much hope of expanding these markets. One exception is the fly ash used in concrete, where it has a high potential value and acts as a replacement for portland cement. Another example is for road base material where fly ash is used because of its pozzolanic reactivity. Thus, in these applications fly ash has sufficient value that it can be economically transported and has much larger potential application. Fly ash in cement and concrete was the subject of a previous EPA study, while this study will focus on the road base applications.

PRODUCTS MADE FROM POWER PLANT ASH

Descriptions

Fly Ash as Mineral Filler in Bituminous Pavements. The importance of mineral fillers in bituminous paving has been recognized for many years. Asphalt paving mixtures have been designed to include mineral filler since 1890. The term mineral filler generally applies to the fine fraction of a conventional aggregate that is predominantly a fine mineral dust.

Mineral fillers in asphalt paving mixtures are particles suspended in the asphalt binder which serve to improve the cohesion of the binder itself while contributing to the internal stability of the mixture by increasing the contact points between aggregate particles. When incorporated in an asphalt mixture, mineral filler greatly increases the surface areas that must be coated with asphalt. If these surfaces are compatible with the asphalt and are easily coated, use of the filler produces considerable benefits. Fly ash meets these requirements.

The benefits of fly ash as a mineral filler has been pointed out by many investigators. The principal benefits are increased stability and better durability, both of which are attributable to absorption. Increased stability results from a stiffened binder, while better durability is related to the character of the absorbed film. Fly ash has been proven effective in imparting those properties.

In fact, a review of previous research data in Part I, Volume 2, of this study, clearly indicates that fly ash is not only technically suitable for use as a mineral filler, but is also a superior product for this purpose.

Most fly ashes are able to readily conform to existing specification requirements for mineral fillers. Several million tons of fly ash have been used as mineral fillers in more than 22 states over the past 40 years with more than satisfactory results. Furthermore, the relatively high lime content of western (lignite and sub-bituminous) fly ashes is an added feature which appears to impart anti-stripping properties to asphaltic concrete mixtures, as well as retarding the age hardening of the asphalt binder.

In addition to technical considerations, use of fly ash as mineral filler is dictated by economics. In many areas where suitable fly ash is available, it is considerably lower in cost than hydrated lime, which now is selling for $50 or more per ton. Fly ash is also available in many densely populated areas, where demand for asphalt paving is presumably greatest.

At the present time, utilization of fly ash as a mineral filler in asphalt paving mixtures does not represent a significant use area for the material. Moreover, the actual quantities used for this purpose have remained relatively constant over the past ten years. Increasing quantities of baghouse dusts from air pollution control in hot-mix asphalt plants (and kiln dust from cement and lime plants which are also being used as mineral fillers) are now competing with fly ash as potential sources of filler material. It is possible that the national market for fly ash filler may even be in decline and that overall demand for mineral fillers may continue to diminish. This is because many hot-mix asphalt producers prefer to recycle the baghouse dusts from their plant internally as fillers rather than use outside filler sources.

The use of fly ash as a filler does not have potential growth, and it does not appear to be an application that will contribute significantly to alleviating the growing solid waste problem. Therefore, this application is not recommended for further consideration for a procurement guideline.

Power Plant Aggregates in Base Course or Bituminous Paving Material. Bottom ash and boiler slag can be utilized as aggregates in road construction applications, either in stabilized base courses or in bituminous paving mixtures. However, in these applications the power plant ash has a relatively low value as it is competing against sand and gravel and is restricted in use to locations generally quite close to power plants.

Use of power plant ash in these applications is technically proven, as shown in Part I, Volume 2 of this report. However, power plant aggregates are presently utilized at fairly high levels in terms of percent of total generation.

In the states of West Virginia, Ohio, and Indiana these materials are particularly well utilized for all of the applications mentioned. However, there are frequent reports of problems with lack of availability, especially for use as aggregates. Use in ice control is frequently a primary use. Thus, the materials are used when available, but frequently the supply cannot be considered dependable.

While it is recognized that stimulating the use of bottom ash and boiler slag in highway construction materials is desirable, the limited potential dictates that fly ash should have priority for consideration. For these reasons, bottom ash and boiler slag will not be considered further in this report.

Fly Ash in Structural Fills. One useful application of fly ash is as a replacement for earth in structural fills and embankments. This is discussed in detail in Part I of Volume 2.

It is evident from the review of available literature pertaining to fly ash use as an embankment or structural fill material that fly ash is unquestionably suitable for such use and, in addition, provides certain unique and beneficial properties when utilized in such applications. Of particular advantage is the relatively low density of the material combined with substantial shearing strength and long-term strength gaining characteristics. Moreover, compacted fly ash has a low permeability, particularly if it is self-hardening, and indications thus far are that the material is not subject to leaching of potentially hazardous concentrations of inorganic chemicals.

Prospective users of fly ash as a fill material should be aware of the potential for frost susceptibility. Furthermore, the placement of fly ash in a fill or embankment must be accomplished above the anticipated high water table and the material must be underlain by a drainage blanket or open-graded granular material. Precautions must be made to keep the fly ash sufficiently moist while spreading and compacting in order to avoid excessive dusting and all exposed sloping surfaces of the fly ash must be covered with soil to protect against erosion.

In spite of the preceding precautions, an objective engineering assessment of the use of fly ash for embankment and structural fill purposes leads to the conclusion that this material is well suited for such purposes. Indeed, fly ash has been used extensively and successfully as highway fill and backfill material throughout much of Great Britain for many years and its excellent performance in many British highway projects has been repeatedly documented. In those few instances where fly ash has been used as highway fill material in the United States, its record of performance has also been outstanding.

During April 1980, a questionnaire was circulated to all state highway departments by The American Association of State Highway and Transportation Officials (AASHTO). The questionnaire requested information on uses, extent, performance, and attitudes related to different recovered materials in highway construction in each state. Results of this questionnaire indicate that a total of 8 states have made, or are making use of fly ash in an embankment or structural fill. These states are Arizona, Illinois, Minnesota, New York, Ohio, West Virginia, Wisconsin, and Wyoming. All of these states rated the material's performance in this application as either acceptable, good, or excellent. Each of these states plans to make further routine use of fly ash as an embankment or structural fill material, except that Minnesota feels that more field study should be made in connection with such use.

Aside from lack of knowledge about the usefulness of fly ash and some of its unique characteristics, the biggest obstacle to more widespread use as highway fill material in this country is logistics. Most highway construction projects are designed so that there is practically a balance between cuts and fills and as little "borrow material" as possible is required. Except for those occasional situations where a large stockpile of ash may be located relatively close to a highway project, in most instances, the use of excavated earth from the project site will be more convenient, available, and economical. Moreover, as the construction of new highway alignments diminishes, there will most likely be less future opportunities to utilize fly ash as a highway embankment or fill material.

For these reasons, development of procurement guidelines for the use of fly ash as a structural fill material does not appear to be warranted. However, further efforts should be made to educate highway engineers, road-building contractors, and other interested parties concerning the advantages offered by fly ash in the construction of fills and embankments so that, when opportunities to make use of this material do arise in the future, fly ash will receive favorable consideration and not be discriminated against because it is unlike soil. The relative economics and logistics of each site-specific situation should be the determining factors in deciding whether fly ash use as highway fill material is most suitable and advantageous for a particular project.

Fly Ash in Stabilized Base Course Materials. One of the most successful and promising applications for the use of fly ash in highway construction is in lime-fly ash-aggregate (LFA) base or sub-base mixtures. These mixtures are blends of commercial lime, fly ash, and mineral aggregates, combined with water in the proper proportions and compacted to form a dense, stable mass. Mixtures of lime, fly ash, and aggregate, and in some cases additional portland cement, are often referred to as pozzolanic pavements. These mixtures may also involve substitution of kiln dusts in place of lime or cement, which is discussed in another section of the report.

Fly ash is suitable for this application because of its pozzolanic properties. A pozzolan is defined as a siliceous or aluminous and siliceous material which is in itself chemically inert, and possesses little or no cementitious value, but, when in a finely divided form and in the presence of water, will react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties. The term pozzolan is derived from the Latin word "pozzuolana," which referred to a volcanic ash found near the town of Pozzuoli, Italy, where the mixture of volcanic ash with a crude lime was first discovered in 350 B.C. and used as a matrix for Roman building materials.

The most commonly available pozzolan in use in the United States at this time is fly ash. Because of the basic variations in coals from different sources, along with design differences in coal-fired boilers, not all fly ash is the same. While there are differences in fly ash from one plant to another, day to day variations in the fly ash from a single plant are usually quite predictable, provided plant operation and coal source remain constant. It should be pointed out that fluctuations in the chemical composition of fly ash are far less critical for use in LFA base materials than in portland cement concrete.

Essentially, what occurs in a pozzolanic reaction is that calcium from the lime and silica from the pozzolan (normally fly ash) react in the presence of water to form a gelatinous calcium-silicate compound, which provides a cementitious binder for the aggregate particles in the mix. The pozzolanic reaction is time and temperature dependent, so that different compounds may be in varying stages of formation, depending on the length of time the reaction has been progressing or the temperature conditions to which the component materials have been exposed.

Most western (lignite and sub-bituminous) coal fly ash contain higher concentrations of free lime (CaO) and sulfate (SO_3), resulting in the formation of other cementitious reaction products such as ettrignite (calcium sulfo-aluminates). Such reactions are related to portland cement chemistry and offer opportunities to use higher fly ash dosages in LFA mixtures.

The initial discovery of a pozzolanic reaction between fly ash and lime and its subsequent use in the stabilization of fine-grained soils was made by engineers from The Special Tests Branch of the Philadelphia Electric Company during the mid-1940s. This discovery subsequently became the basis for three patents on the stabilization of soils using lime-fly ash reactions. Copies of these patents are included in the Appendix of this report in Volume 2.

As a followup to this work, the G. and W. H. Corson Lime Company, under the sponsorship of Philadelphia Electric Company, began research on the use of lime-fly ash pozzolanic reactions with aggregates and soil-aggregate mixtures.

With the issuance of a patent for "Poz-O-Pac," and the establishment of a licensee arrangement for the production of the material, pozzolanic base materials were eventually produced and placed in construction projects in at least a dozen states.

The use of fly ash in LFA is a technologically sound application, and is a use where fly ash has a high value. Also, the potential for use in that application is widespread. This product is the most important potential application of power plant ash, and will be the focus of data development and analysis in this chapter.

Cement Stabilized Fly Ash Bases and Sub-Bases

Another means of using fly ash in road construction is as a cement stabilized road base or sub-base material in highway construction. This can be done by stabilizing fly ash with portland cement (or, in some cases, hydrated lime). Cement-stabilized fly ash base course and sub-base materials are used in flexible pavement systems in the same manner as lime-fly ash-aggregate and other pozzolanic base materials, except that the cement-stabilized fly ash mixtures do not contain any conventional aggregate.

One of the most obvious advantages to the utilization of cement-stabilized fly ash as a highway base course or sub-base is that between 80 to 90 percent by weight of the base course or sub-base material is fly ash, instead of from 10 to 25 percent, as is the case with most lime-fly ash-aggregate or other pozzolanic compositions. Thus, use of cement-stabilized fly ash mixtures results in a substantially greater utilization of fly ash.

Cement-stabilized fly ash base course material has been used on a very limited basis in the United States. Although substantial use has been made of this material in some European countries, and the necessary design procedures and specifications for its use in this country have been published in the form of a manual by the National Ash Association, the material, itself has only been placed in a handful of projects. Consequently, although cement-stabilized fly ash is similar to that of lime-fly ash-aggregate or soil-cement base materials and the material appears to have a proven record of performance, most engineers, and in particular, road-building contractors, are still not familiar with this material. Therefore, experience in the United States with cement-stabilized fly ash is simply not sufficient to utilize the product on a routine basis at this time.

Despite the performance record of cement-stabilized fly ash in Great Britain, it is not appropriate to expect a rapid transfer of testing, design, and construction procedures, as well as specifications, to be made on the part of American engineering practice with a comparatively untried material. In order to gain product acceptance and incorporate the use of cement-stabilized fly ash base materials into American construction use, a program involving several years of laboratory investigation and monitoring of field performance must be undertaken by a number of Federal and state agencies. Only when confidence in this material has been gained through actual experience can any consideration be given to possible development of guidelines for its use.

This product will not be considered further in this study, but the reader is referred to Part I, Volume 2, for a detailed analysis of cement-stabilized fly ash in these applications. However, EPA may want to evaluate the status of this product by 1985 for possible consideration of additional study for procurement guidelines.

COMMERCIAL AVAILABILITY OF LFA

Recently, the "Poz-O-Pac" patents have expired, although there are still a number of producers that continue to sell pozzolanic base course materials, especially east of the Mississippi River. The rights to the use of the tradename "Poz-O-Pac" west of the Mississippi are now vested with City Wide Asphalt Company of Kansas City, Missouri. A subsidiary company (Road Base, Inc.) produces a pre-blended LFA product, in which the lime and fly ash are blended and stored prior to mixing with aggregate. This product is called "Poz-O-Blend." This product is described in Appendix A, Volume 2.

Throughout the years, it is estimated that approximately 25 to 30 million tons of LFA or pozzolanic base course materials have been produced and placed in the United States since 1950 which implies a substantial commercial availability of LFA. There have been large quantities of LFA used in three states--Illinois, Ohio, and Pennsylvania. In seven other states--Colorado, Maryland, Michigan, North Dakota, South Dakota, Texas, and Virginia--LFA has received at least limited field use and is assumed to be commercially available.

LFA is relatively easy to manufacture. All that is needed are silos for storage of the raw materials, conventional mixing equipment, and some provision for adding water. Thus, manufacturers of asphalt-concrete or portland cement concrete frequently have much of the equipment, if not all, in place. What equipment they don't already have is relatively inexpensive. Thus, ownership of the manufacturing equipment is not the primary deterrent to commercial availability.

The primary limiting factor for potential commercialization is the availability of suitable raw materials--lime, fly ash, and aggregate. In most parts of the country (but not all) suitable aggregates can be found, because LFA can utilize a wide range of different aggregates. Thus, commercial availability depends primarily on the availability of lime and fly ash, although portland cement or kiln dust can be used in place of lime to activate fly ash.

Figure 5-3 shows the potential areas for LFA commercialization. The shaded zones represent areas located within 200 miles of lime plants and 50 miles of coal-fired power plants. Industry representatives feel that these areas represent "most likely" places where LFA could be potentially produced because of desirable logistics. However, if facilities exist for rail transport and eventual stock piling of conditioned fly ash, even greater distances are possible since the problem of resupplying storage silos is eliminated. In addition, areas where conventional materials may be quite

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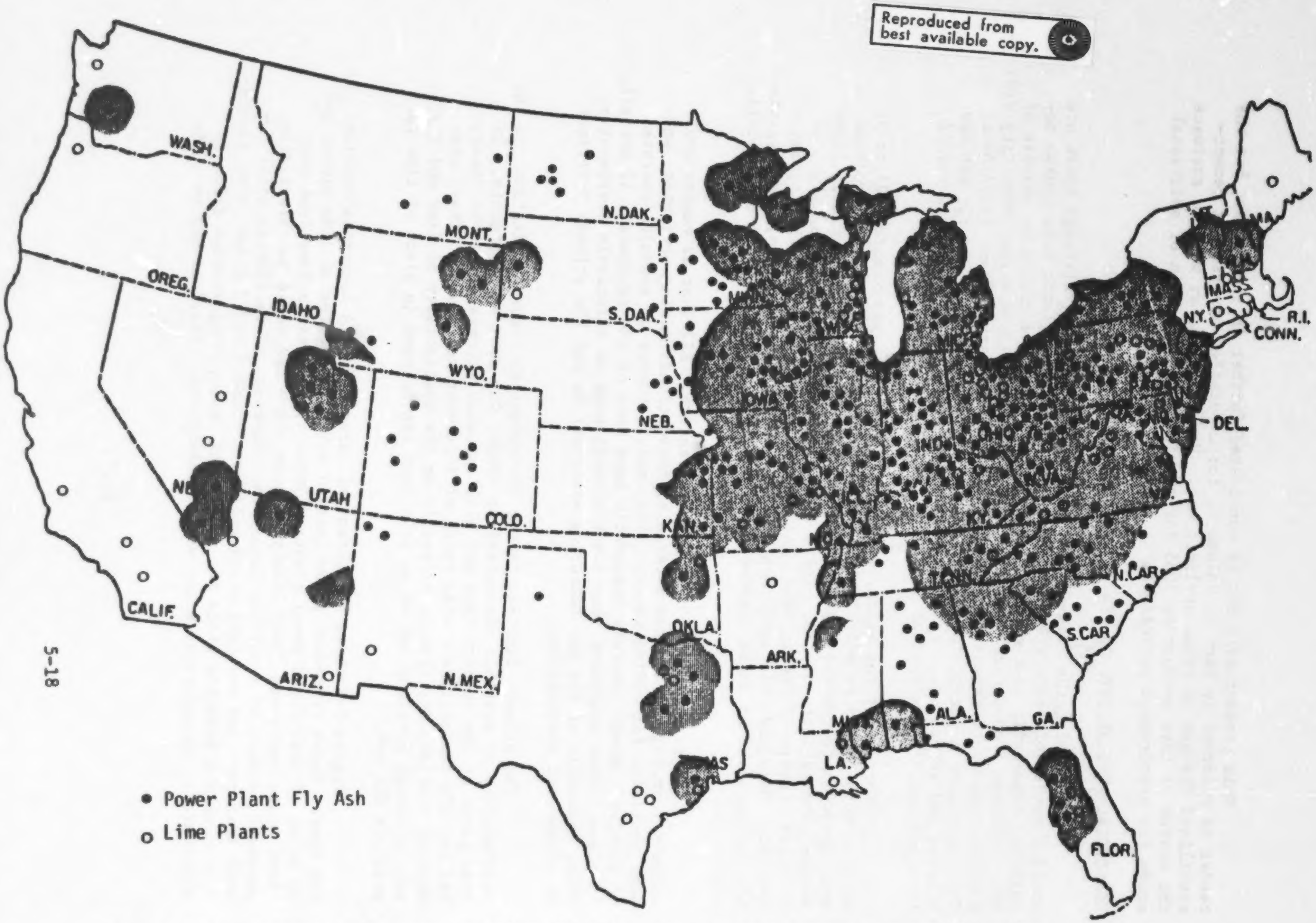
WASH.
OREG.
CALIF.
IDAHO
NEV.
UTAH
ARIZ.
MONT.
WYO.
COLO.
N.MEX.
N.DAK.
S.DAK.
NEB.
KAN.
OKLA.
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S.CAR.
N.CAR.
VA.
W.VA.
PA.
N.Y.
DEL.
MASS.
R.I.
CONN.
VT.
N.H.
MA.
● Power Plant Fly Ash
○ Lime Plants

Figure 5-3. Most probable areas of lime-fly ash-aggregate base course commercialization.

expensive or where aggregates are poor in quality are additional locations for potential commercialization. As can be seen from the figure, the greatest potential for commercilization exists in the eastern half of the U.S., but significant potential exists in selected areas of the western half. In fact, most states have at least some potential for LFA commercialization.

The findings of a questionnaire on recovered material usage, which was circulated by AASHTO to all state highway materials and construction engineers during April 1980, show that a total of 14 states have at some time used LFA compositions in base course or shoulder applications. Six of these 14 states presently include LFA in their state specifications. One state (West Virginia) used to have a special provision in its state specifications for lime-fly ash-aggregate base, but reports that it was discontinued due to lack of interest by the contracting industry. Instead, West Virginia uses cement-treated base to a significant degree.

States indicating some use of LFA base materials are:

Arizona
*Colorado
*Illinois
Maryland
Massachusetts
Michigan
Missouri
*New Jersey
*North Dakota
*Ohio
Oklahoma
*Pennsylvania
Texas
West Virginia

In addition to the 14 states noted above, at least four other states are presently evaluating LFA compositions in the laboratory. These states are Georgia, Mississippi, New York, and North Carolina. Of these four states, only North Carolina felt that LFA behaved poorly in the lab because "the strength of lime-fly ash stabilization of aggregate base at 7 days was 12 percent of the aggregate base with 3 percent cement and was 3 times as expensive" (Reference 5-2).

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* States which have a specification for lime-fly ash-aggregate. The only states reporting routine use of LFA are Illinois, Ohio, and Pennsylvania. Most of the remaining 11 states report that LFA base has been used in government-funded projects only on a limited field basis (less than six projects) or as a field experiment (one or two small test sections). Generally speaking, LFA materials have been used to a greater extent on local facilities than state highways.

A review of technical reports and promotional literature on stabilized road base materials confirms that LFA mixtures have also been placed in several other states, including Delaware, Indiana, New York, South Dakota, and Virginia. Since none of the DOT personnel in these states has indicated use of this material in their questionnaire responses, it is assumed that LFA use in these states has been confined to local roads and/or private projects, with no use in state or federally funded highway construction.

Of the 14 states reporting LFA use, 10 consider the performance of the material to have been either acceptable, good, or, in the case of three states, excellent. These three states are Ohio, Texas, and West Virginia. Reasons cited for excellent performance are the pozzolanic activity of lime and fly ash, strength gain with age, and good mixing and compaction in the field. Three states (Maryland, Massachusetts, and Missouri) have experience with LFA materials on a very limited basis in the field and felt that more study was necessary before being able to evaluate the performance of the material. One state, Michigan, considered that LFA base performed poorly on a job because the material showed "temperature and moisture sensitivity for cure, frost susceptibility, poor drainability, and was more expensive than conventional aggregate mixtures" (Reference 5-3).

Referring again to Figure 5-3, page 5-18, which is a map of the United States showing the locations of all coal-fired power plants and all commercial lime plants, all areas shaded on the map are considered as potential use areas for LFA base material usage. Significant portions of 24 states have been shaded in on this map, indicating areas where supplies of LFA component materials (lime and fly ash) are available within a reasonable hauling distance. Considering the 14 states that have reported LFA use by the AASHTO questionnaire, plus five additional states where local or private use of LFA material can also be verified, LFA base materials have been used to some extent in at least 19 states. This total represents approximately half of all states which could possibly be using this material. Table 5-4 lists the 34 states where there is some potential for use of LFA base materials from the standpoint of lime and fly ash availability and also indicates those 19 states where there has been known use of these materials.

Of these 19 states, there are probably only three (Illinois, Ohio, and Pennsylvania) that are faimilar enough with the characteristics and performance of LFA base that they would be able to award more contracts using this material without additional laboratory testing and field monitoring of the material. With few exceptions, most of the remaining 16 states would probably need to spend some time for further evaluations of LFA base before feeling ready to proceed with a substantially higher degree of LFA use in highway construction.

Table 5-4

ACTUAL AND POTENTIAL USE PATTERNS OF LIME-FLY ASH-AGGREGATE BASE COURSE

EPA Region 1

		Maine
	•	New Hampshire
	•	Vermont
*		Massachusetts
		Connecticut
		Rhode Island

EPA Region 2

*	•	New York
*	•	New Jersey

EPA Region 3

*	•	Pennsylvania
*	•	Maryland
*	•	West Virginia
	•	Virginia
		Dist. of Columbia
*	•	Delaware

EPA Region 4

	•	Kentucky
	•	Tennessee
*	•	North Carolina
	•	South Carolina
*	•	Mississippi
	•	Alabama
*	•	Georgia
	•	Florida

EPA Region 5

	•	Minnesota
	•	Wisconsin
*	•	Michigan
*	•	Illinois
	•	Indiana
*	•	Ohio

EPA Region 6

*	•	Texas
		New Mexico
*	•	Oklahoma
		Arkansas
		Louisiana

EPA Region 7

	•	Kansas
*	•	Missouri
	•	Iowa
		Nebraska

EPA Region 8

		Montana
*		North Dakota
	•	South Dakota
	•	Wyoming
	•	Utah
*		Colorado

EPA Region 9

		California
	•	Nevada
*	•	Arizona

EPA Region 10

	•	Washington
		Oregon
		Idaho

*	Actual
•	Potential

QUALITY CONTROL

The assurance of quality is a critical aspect of any successful installation of a highway construction product. The mixing and installation of LFA poses no particular problems as long as a good mix design and sound construction techniques are used. However, the primary problem unique to LFA is the quality control of fly ash. Lime is a manufactured product, and quality can be readily assured. However, fly ash is too often viewed as a waste product, and quality must be carefully monitored. Quality control is usually done by the ash marketer who samples frequently and works closely with the power plant staff.

Quality requirements for the use of fly ash and other pozzolans with lime in plastic mortars and non-plastic mixtures are contained in ASTM C593-76a, "Standard Specification for Fly Ash and Other Pozzolans for Use with Lime."

In addition to meeting that specification, many state and Federal transportation agencies also specify that the fly ash have a maximum loss on ignition value of 10 percent when determined in accordance with the procedures of ASTM C311. Although ASTM C593 has set no limit on the loss of ignition value for a pozzolan when used with lime, such a provision would be desirable.

The pozzolanic reactivity or lime-pozzolan strength of fly ash is the best indicator of its ability to form cementitious compounds in LFA mixtures. The pozzolanic reactivity of fly ash is dependent on the following factors, which must be carefully controlled.

1. Fineness--the larger the percentage passing the -325 mesh sieve, the greater the surface area and pozzolanic reactivity.
2. Silica and alumina content--the higher the silica, or the silica and alumina, the more reactive the fly ash.
3. Loss on ignition or carbon content--the lower the loss on ignition, the higher the pozzolanic reactivity of the fly ash.
4. Alkali content--the higher the alkali content, the more reactive the fly ash.

Quality control of these variables is readily achieved by competent ash marketers.

Since the major portion of an LFA mixture is composed of aggregate, the quality of the final product is dependent to a large extent on the aggregate used. Thus, quality control of the aggregate is important. A wide variety of aggregate types and gradations have been used successfully in LFA compositions. These include crushed stones, sands, gravels, bottom ash, boiler slag, and several types of ferrous slags. Whatever the type and source of aggregate used, the gradation of the aggregate should be such that, when mixed with lime, fly ash and water, the resultant mixture is mechanically stable and capable of being densely compacted in the field. Furthermore, any aggregate used in LFA base mixtures should consist of hard, durable particles and be free from any deleterious chemicals or organic substances that could interfere with the desired pozzolanic reactions within the mixture.

Most, if not all, state and Federal transportation agencies that specify LFA mixtures also specify the quality requirements and range of acceptable gradations for aggregates to be used in such mixtures. There are not any unusual problems in monitoring aggregate quality control.

LOCATIONS OF PRODUCERS

As shown in Table 5-5, about 80 percent of the LFA produced in this country is in the Chicago area, mostly by one producer. However, producers also exist in other states. Since the expiration of patents on "Poz-O-Pak," a complete list of producers is not available. However, every state that reports at least limited field use of LFA must have either a producer in the state, or in an adjacent state. Those states are shown in Figure 5-3 and represent the approximate locations of producers.

CURRENT USE PATTERNS

As discussed previously, about 80 percent of the current use is in the Chicago area. The other 20 percent are in widely scattered locations in the U.S., as shown in Figure 5-4. The amounts used in each location are not known. However, as noted earlier, use of pre-blended LFA material is increasing in the Kansas City area.

POTENTIAL USE

It is estimated that 738,000 tons of LFA was produced in 1979 (Table 5-5). If fly ash is used at the rate of 12 percent of the final material, then 89,000 tons of fly ash was used. This is on the order of two-tenths of one percent of the 57.5 million tons of fly ash generated in 1979, and therefore was an insignificant use of fly ash on a national scale.

Because LFA has not yet achieved much more than moderate use, any calculations of potential use are little more than quite rough estimates. However, in order to determine if use of fly ash might even remotely be of importance, a ballpark calculation can be made. LFA can be considered as primarily a replacement for hot-mix asphalt base. In those applications, it can be assumed that 1.1 tons will functionally replace 1.0 tons of asphalt base. If LFA utilizes 12 percent fly ash, then 0.13 tons of fly ash will be used for each ton of asphalt base replaced.

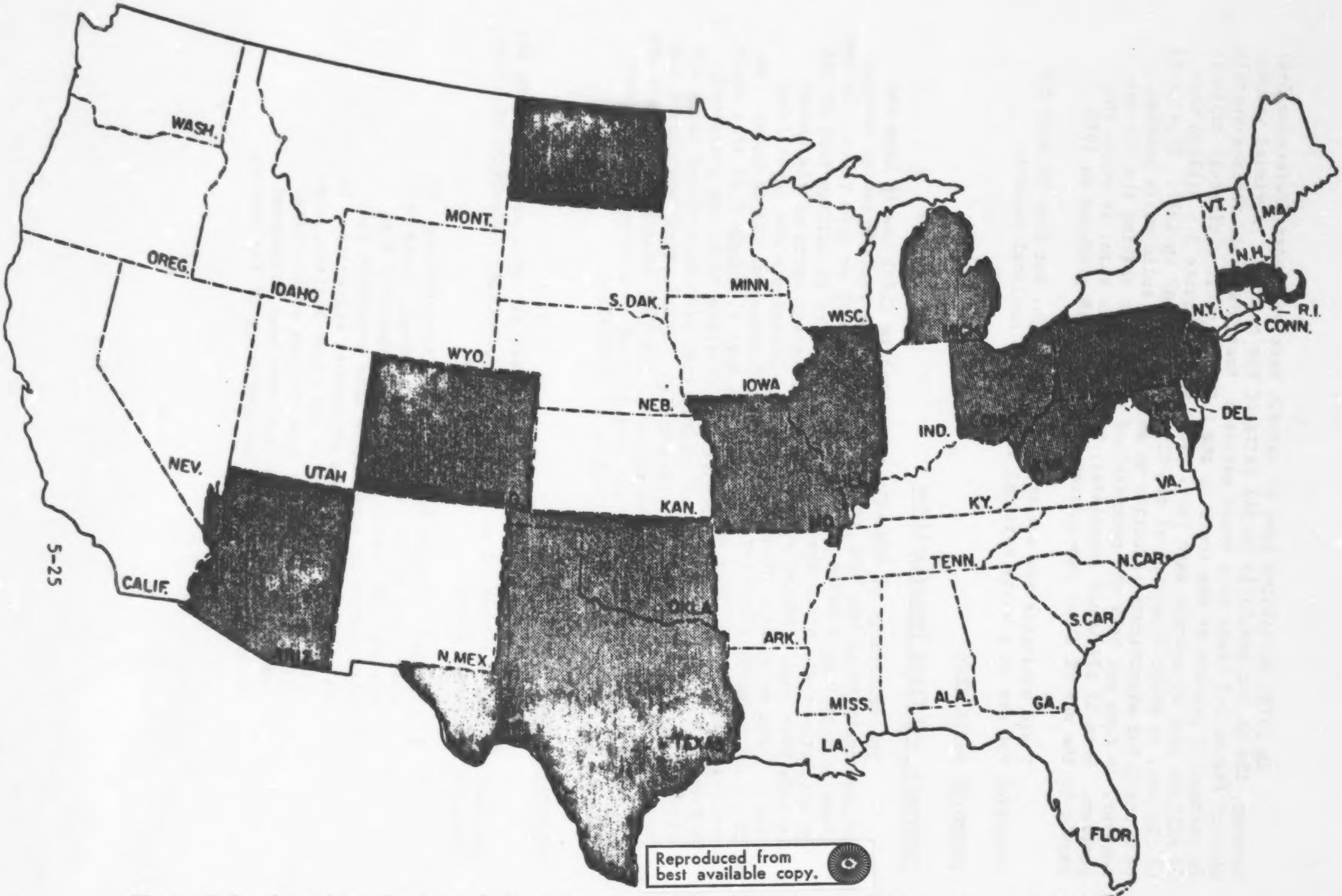
Table 5-5

ESTIMATED ANNUAL PRODUCTION OF LIME-FLY ASH-AGGREGATE BASE MATERIAL IN THE UNITED STATES

Year	Total LFA Production	LFA Production In Chicago Area	Percent - Production In Chicago
1970	-	660	-
1971	-	1,010	-
1972	-	490	-
1973	1,050	660	62.9
1974	778	660	84.8
1975	610	500	82.0
1976	801	680	84.9
1977	736	630	85.6
1978	755	650	86.1
1979	738	600	81.3

Note: Poz-O-Pack patents expired in 1979.

Source: I U Conversion System, Inc., Horsham, Pennsylvania and American Fly Ash Company, Chicago, Illinois.


WASH.
OREG.
IDAHO
MONT.
WYO.
S. DAK.
MINN.
WISC.
IOWA
NEB.
NEV.
UTAH
CALIF.
ARIZ.
N. MEX.
KAN.
OKLA.
TEXAS
ARK.
MISS.
LA.
ALA.
GA.
FLOR.
TENN.
KY.
IND.
MO.
MICH.
OHIO
VA.
N. CAR.
S. CAR.
DEL.
N.Y.
VT.
MA.
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R.I.
CONN.

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Figure 5-4. Location of states indicating use of lime-fly ash-aggregate base materials.

In 1978, 90 million tons of asphalt base were used (Reference 5-4). However, LFA is not available in all parts of the country. A visual inspection of Figure 5-3 leads to a rough estimate that LFA could replace asphalt in perhaps 30 percent of the roads in the U.S., or could ultimately replace 27 million tons of asphalt each year. This would require 3.5 million tons of fly ash, or about 6 percent of the fly ash generated in 1979. This would be a small but significant reduction in an important solid waste problem. However, it does not have the potential of completely solving the fly ash problem. Even if LFA would completely replace black base, it would only result in the use of about one-quarter of the fly ash produced in 1978.

These estimates are admittedly quite rough, but they do show the potential for use of a waste material which is of national concern.

TECHNICAL ASSESSMENT

Laboratory and Field Investigations

The technology of lime-fly ash-aggregate (LFA) use in base and sub-base construction has been well documented, and implemented to various degrees in more than a dozen states over the past 20 or more years. It has been estimated that, since the mid-1950s, from 20 to 25 million tons of LFA materials have been produced and placed in different parts of the United States. There is a large amount of published literature and unpublished data on composition, characteristics, and performance of LFA mixtures. An extensive discussion of this may be found in Part I, Volume 2 of this study, where laboratory investigations and results of field tests are presented. There are hundreds of sections of roadway that have been placed using LFA base materials and which have provided highly satisfactory performance for many years. These projects are testimony to the fact that LFA materials are indeed suitable for use as road base compositions on primary and secondary highways, as well as in the construction of airfields.

Advantages and Disadvantages

The use of LFA material in areas where it is available offers the prospective user a number of advantages. The principal advantages of these products are listed below.

1. The most obvious benefit of LFA compositions is cost. All other factors being equal, these materials are nearly always less expensive than alternative or competitive base materials such as bituminous concrete or crushed aggregate. In these times of inflation and tight budgets, significant cost savings from the use of LFA bases are not only possible, but have been documented on numerous occasions in many areas of the country.

2. A pozzolanic reaction occurs in these compositions, resulting in gradual, long-term strength development over time. This strength development can be controlled and designed into the mixture by altering the formulation during mix design. One of the most effective ways to monitor material quality control and incorporate component material properties into the mix design is by the pre-blending of lime and fly ash, which is currently being done in the production of "Poz-O-Blend" material in the Kansas City area. In this way, mix formulations can be readily adjusted to compensate for variations in fly ash and/or aggregate quality.

3. Ultimate strength development of LFA base is comparable to that of low-strength concrete. There have been many examples where the ultimate strengths of LFA materials have exceeded 3,000 psi and in some instances have even achieved 5,000 psi or higher strengths. In terms of cost per psi of strength developed, LFA provides more strength for the dollar than any other paving material.

4. LFA base materials are relatively easy to install and can be placed and compacted with conventional construction equipment. There is no need for any exotic hardware or fancy procedures when mixing or laying LFA materials.

5. In states where LFA has been most frequently used, the structural design coefficients for the material are equal, or nearly equal, to bituminous base and substantially higher than crushed aggregate.

6. The use of LFA base provides an excellent opportunity to utilize a material that is considered a disposal problem to the electrical utility industry. From the perspective of fly ash utilization, one cubic yard of concrete can use 100 pounds of fly ash, while one cubic yard of LFA can use 400 pounds of fly ash. In pozzolanic mixtures containing sludge materials, one cubic yard of mix may contain up to 1,000 pounds of fly ash.

7. Once the material ages beyond the first winter, it continues to develop strength at a rate which exceeds the accumulated wheel loadings being applied to the road. Consequently, LFA pavements rarely fail from fatigue. Moreover, it has been determined that, on low traffic volume facilities, LFA mixtures with well-graded aggregates possess sufficient mechanical stability to support wheel loadings through the first winter, even if no cementing of the base occurs.

8. LFA materials contain fly ash, which is not an energy intensive material. Therefore, use of LFA results in reduced energy input compared to that of alternative materials. Substitution of LFA base in lieu of bituminous base would not only result in lowered costs, but would conserve needed petroleum resources.

On the other hand, there are certain disadvantages associated with LFA materials which must also be considered. The main disadvantages of this product are:

1. On state and Federally funded highway construction work, there are recommended construction cutoff dates which are part of the material specifications. In northern states, where most of the LFA materials have been used, the material is not permitted to be installed on state projects beyond a specified date, usually sometime between September 15th and October 1st. These days may or may not be overly conservative, but their net effect is to reduce the length of the construction season for LFA placement. On municipal projects, LFA has often been installed well beyond applicable state highway cutoff dates with no failure.

2. LFA base materials are not specified on many reconstruction projects where maintenance of existing traffic is necessary because, in the minds of many highway engineers, the material does not always hold up particularly well to heavy traffic (especially truck traffic). This is more of a problem immediately after the material has been placed and compacted. It is normal practice to blacktop over LFA base as soon as possible (within one or two days) after it has been installed.

3. The production of LFA at the plant, as well as its placement at the job site, requires some reasonable quality control to assure a good performing product. This material is sensitive to variations in moisture which, if large enough, would adversely affect compaction and eventual job performance. This cannot be achieved unless the product comes out of the plant at or close to its optimum moisture content and is properly compacted. As noted previously, improved product control can also be attained through preblending.

4. To many engineers, fly ash is a waste material, and not a product. When viewed as a waste material, fly ash is considered to be variable and of low quality. While in some cases this may be true, there are many acceptable sources of fly ash available for LFA use. Again, quality control of the ash and cooperation with the utility company is essential. The quality requirements for use of fly ash in LFA materials are far less stringent than for the use of fly ash in portland cement concrete.

In objectively weighing the advantages vs. the disadvantages of LFA base materials, on balance, the good points of this material definitely outweigh its bad points. It is a proven fact that, if this material is designed, produced, and placed properly, it performs well. It is a versatile product, having been produced with almost every kind of aggregate and dozens of different sources of fly ash. The further option of pre-blending lime and fly ash allows a producer the flexibility for compensating for the variations in fly ash quality by adding more lime, rather than being constrained with a single job mix formulation. The mix formulations can also be varied to add more lime and fly ash to aggregates of lower quality.

The obvious advantage that LFA base offers in dramatic cost savings is, in and of itself, a compelling enough reason for justifying more widespread use of this material.

All of the disadvantages cited above can in one way or another be overcome by applying good, sound engineering coupled with a firm commitment to product quality control. Therefore, from a technical and economic standpoint, use of LFA base is not only justifiable, but also very beneficial.

SPECIFICATIONS

Standard Specifications

Even though it has had a long history of use in road base applications, and extensive use in some locations, there are as yet no guide specifications for LFA. However, ASTM has specifications for the components of LFA, as listed in Appendix A of Volume 2.

State Specifications for Routine Use

In most states where LFA has been used, a supplemental specification based on standard specifications has been used, and these specifications have not been institutionalized to the extent that they have been made a part of the routine specifications. In Illinois where most of the LFA has been used, the supplemental specification first developed in 1961 has been revised eight times, but is still carried as a supplemental specification. In Ohio, the specifications were left in the supplemental form originally because it was a patented product. However, the patents have expired, but there is a low degree of interest in using LFA at present so the specifications will likely remain as a supplemental provision until more interest develops. The one state known to have standard specification for routine use is Pennsylvania. Its specification was adopted in 1966 and has remained unchanged.

COSTS

Producers and Suppliers

The incremental cost of LFA base to producers and suppliers is minimal when compared to other construction materials. In order to produce LFA, the capital investment is small. All that is needed is storage facilities for the lime and fly ash, and simple blending equipment. It is reported that $300,000 to $500,000 would be needed for purchase and installation of new equipment, and that this investment would be paid back quite rapidly. However, most prospective producers have some storage facilities that would be suitable, or can buy used equipment at a substantial savings. In one case, a plant was reportedly converted for $115,000. Thus, it is concluded that the cost of setting up production facilities is not a deterrent to use of LFA.

Customers

A more important question concerns the cost of LFA to customers. That is, can LFA result in lower bid prices for road construction?

In this section, the relative economics of using base materials are compared with the costs of using competitive base course materials in the states of Illinois, Ohio, and Pennsylvania. The competitive base course materials studied are bituminous concrete base and crushed stone base. Comparisons are made between actual bid prices for each type of base. The bid price data were obtained from Department of Transportation (DOT) personnel in each of these three states.

To analyze these comparative costs in each state, a pavement design example was developed assuming a structural number* of 4.00 in order to determine design thicknesses for each of the three pavement options. Based on the required thickness of each material and its compacted density, a square yard price was then determined for each wearing surface and base course material combination in a given state. The following compacted densities are assumed for each of the paving materials used:

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* Structural number is a design value developed from road tests relating to the overall structural capacity of a pavement.

Wearing surface - 150 lbs/ft^3
Bituminous base - 145 lbs/ft^3
Pozzolanic base - 140 lbs/ft^3
Aggregate base - 125 lbs/ft^3

The three pavement alternates are compared in terms of estimated total in-place costs. Cost comparisons are discussed for each of the three individual states. An overall comparison is then made of costs from each of the three states.

1. Illinois

For a pavement structural number of 4.00, use of Illinois flexible pavement design coefficients and AASHTO recommended minimum wearing course thicknesses results in the following basic designs:

Bituminous Base	Pozzolanic Base (LFA)	Aggregate Base
3" Wearing Surface	3" Wearing Surface	5" Wearing Surface
8.5" BAM* Base	10" PAM** Base	15.4" Stone Base
11.5" Total Pavement	13" Total Pavement	20.4" Total Pavement

* BAM refers to bituminous aggregate mixture.
** PAM refers to pozzolanic aggregate mixture or LFA.

Illinois DOT officials have furnished the following in-place cost figures, based on average of five comparative alternate bids received during 1980 on primary projects in District 1 (Chicago area):

Wearing surface - \$55.80 per cubic yard
Bituminous base (BAM) - \$54.50 per cubic yard
Pozzolanic base (PAM) - \$39.20 per cubic yard
Aggregate base - \$20.45 per cubic yard

Converting these prices to square yard costs, based on the design thickness and compacted density of each material, results in the following:

Wearing surface - \$4.64 per square yard (3" thick)
\$7.74 per square yard (5" thick)
Bituminous base (BAM) - \$12.87 per square yard (8.5" thick)
Pozzolanic base (PAM) - \$10.87 per square yard (10" thick)
Aggregate base - \$8.75 per square yard (15.4" thick)

Using the above figures, the total estimated cost per square yard for each of the three Illinois pavement alternatives is:

	Bituminous Base	Pozzolanic Base	Aggregate Base
Surface	\$ 4.64	\$ 4.64	\$ 7.74
Base	12.87	10.87	8.75
Total	\$17.51	\$15.51	\$16.49

From the above cost data, it appears that pozzolanic or LFA base is the least expensive of the three alternatives, being $2.00 per square yard less than bituminous base in the Chicago area. For a two-lane road 24 feet wide, the projected cost savings attributed to LFA base using these cost figures would be $28,160 per mile less than bituminous base.

During the Illinois Pozzolanic Concrete Association Seminar, held in Chicago in April of 1980, a paper was presented outlining the actual cost benefits realized over a four-year period due to the use of pozzolanic base materials (PAM) in the Chicago area. These PAM materials were bid as alternates to black base (BAM), cement-treated base (CAM), or portland cement concrete base on a total of 15 public paving projects let between April 1976 and the time of the seminar (see Table I-12, Volume 2).

Cost savings resulting from the use of the PAM base alternate ranged from $20,000 to $232,000 per project. Overall, a total of $1,247,588 was saved for these 15 projects, or an average of $83,172 per project. This is in addition to the savings of 10 to 15 percent less aggregate, as well as many thousands of barrels of oil from not using a base with an asphalt binder. Furthermore, it was noted in this study that the total cost for asphalt and cement stabilizing agents is increasing at a greater rate than the total cost of lime and fly ash. Another added cost for the bituminous base or BAM alternative is the cost of fuel consumed to dry and heat aggregates and asphalt cement in the dryer.

2. Ohio

For a pavement structural number of 4.00, use of Ohio flexible pavement design coefficients and AASHTO recommended minimum wearing course thicknesses results in the following basic designs:

Bituminous Base	Pozzolanic Base (LFA)	Aggregate Base
3" Wearing Surface (404)	3" Wearing Surface (404)	5" Wearing Surface (404)
8.4" Black Base (301)	10.5" Pozzolanic Base (835)	16.1" Stone Base (304)
11.4" Total Pavement	13.5" Total Pavement	21.1" Total Pavement

It was noted by ODOT engineers that, even though the design example shows a 3-inch wearing surface over the pozzolanic base, a minimum thickness of 4 inches of asphalt concrete over the 835 base provides a more efficient and durable pavement. Some failures were experienced when using less than a 4-inch thick asphalt layer over a pozzolanic base. Therefore, ODOT has recommended a 4-inch wearing surface and 9.5 inches of pozzolanic base.

Ohio DOT officials also furnished a summary of the costs per square yard for the various materials in this design example, which was based on a 1979 summary of awarded contracts. These cost figures are:

Wearing surface (404) - $ 4.52 per square yard (3" thick)
- $ 6.03 per square yard (4" thick)
- $ 7.53 per square yard (5" thick)
Bituminous base (301) - $11.19 per square yard (8.4" thick)
Pozzolanic base (835) - $ 7.29 per square yard (9.5" thick)
Aggregate base (304) - $ 9.08 per square yard (16.1" thick)

Using the above figures, the total estimated cost per square yard for each of the three Ohio pavement alternatives is:

	Bituminous Base	Pozzolanic Base (LFA)	Aggregate Base
Surface	$ 4.52	$ 6.03	$ 7.53
Base	11.19	7.29	9.08
Total Cost	$15.71	$13.32	$16.61

From the above cost data, the pozzolanic or LFA base alternative is the least expensive, and is approximately $2.40 per square yard less than bituminous base in Ohio. For a two-lane road 24 feet wide, the projected cost savings attributed to LFA base using these cost figures is $33,792 per mile.

An illustration of the actual cost savings that were actually realized on a project where alternate base course bids were received occurred during August 1979 when the City of Toledo accepted two bids for reconstruction of a portion of Heatherdowns Boulevard. The bid summary sheet shows three alternates for base course: 1) bituminous-aggregate base; 2) aggregate-lime-fly ash base; and 3) aggregate base. The summary for the alternate base items, in costs per cubic yard of material in place, were as follows:

	Bidder No. 1		Bidder No. 2	
Base Alternate	Cost per cubic yard	Total cost of base	Cost per cubic yard	Total cost of base
Bituminous-aggregate	$42.00	$383,712	$37.00	$338,032
Aggregate-lime-fly ash	$23.00	$278,803	$26.00	$314,364
Aggregate base	$11.65	$388,604	$12.50	$367,444

The lowest cost alternate was the aggregate-lime-fly ash price of $278,803 from bidder number 1. When compared to the low price of $338,032 for bituminous-aggregate base, this represents a cost savings of $59,229 or a 21.2 percent reduction in base course cost by using aggregate-lime-fly ash instead of bituminous-aggregate. When compared to the low price of $367,444 for aggregate base, a cost savings of $88,641 or 31.8 percent can be realized by using the aggregate-lime-fly ash base.

The total bids for this project were as follows:

Base Alternate	Bidder No. 1	Bidder No. 2	Difference
Bituminous-aggregate	$1,685,884	$1,632,843	+ $53,041
Aggregate-lime-fly ash	$1,580,975	$1,609,176	- $28,201
Aggregate base	$1,690,776	$1,662,255	+ $28,521

The job was awarded to bidder number 1 using the aggregate-lime-fly ash alternate. This alternate saved $51,868, or 3.3 percent of the entire job, compared to bituminous-aggregate. The aggregate-lime-fly ash alternate cost $81,280, or 5.1 percent, less than aggregate base.

3. Pennsylvania

For a pavement structural number of 4.00, use of Pennsylvania flexible pavement design coefficients and AASHTO recommended minimum wearing course thicknesses initially resulted in the following basic designs:

Bituminous Base	Pozzolanic Base (ALP)	Aggregate Base
3" Wearing surface	3" Wearing surface	5" Wearing surface
6.7" BCBC*	6.7" ALP** base	12.9" CABC***

* BCBC refers to bituminous concrete base course.
** ALP refers to aggregate-lime-pozzolan base course or LFA.
*** CABC refers to crushed aggregate base course.

The above designs were reviewed by the PennDOT Bureau of Design. As a result of this review, several changes were proposed to conform to the PennDOT design manual, by taking into account minimum pavement depth, frost design requirements, and the use of sub-base material. Based on these changes, the resultant designs were as follows:

Bituminous Base	Pozzolanic Base (ALP)	Aggregate Base
1.5" Wearing surface	1.5" Wearing surface	1.5" Wearing surface
6" BCBC	2" Binder course	2" Binder course
10" Sub-base	6" Sub-base	10" Sub-base
17.5" Total Pavement	14.5" Total Pavement	21.5" Total Pavement

Analysis of the above designs indicates that the resultant structural numbers for each alternate are slightly different. The BCBC pavement has a structural number of 4.16; the ALP pavement has a structural number of 4.20; and the CABC pavement has a structural number of 4.08.

The following in-place cost figures, derived from the most recent weighted average of all awarded contracts statewide, as published in PennDOT Bulletin 50, with the ALP value revised to reflect current bids.*

1-1/2" wearing surface - $3.30 per square yard
2" binder course - $3.00 per square yard
6" BCBC - $9.20 per square yard
5" ALP base - $6.00 per square yard
8" CABC - $8.00 per square yard
6" Sub-base - $3.75 per square yard
10" Sub-base - $4.15 per square yard

Using the above figures, the total estimated cost per square yard for each of the three Pennsylvania pavement alternatives is:

	Bituminous Base	Pozzolanic Base (ALP)	Aggregate Base
Surface	$ 3.30	$ 3.30	$ 3.30
Binder	-	3.00	3.00
Base	10.20	6.00	8.00
Sub-base	4.15	3.75	4.15
Total Cost	$17.65	$16.05	$18.45

From these data, it appears that the pozzolanic or ALP base is actually the least expensive alternative, being $1.60 less than bituminous base per square yard. For a two-lane road, 24 feet wide, the projected cost savings attributed to ALP base using these cost figures would be $22,528 per mile less than bituminous base.

Additional comparative cost information on ALP base and bituminous base prices was obtained from the City Engineer for the City of Lancaster, who usually asks for alternate bids for all street reconstruction work. Recent bid prices for pavement designs consisting of 1-1/2 inches of asphalt wearing surface, 6 inches of bituminous base, and 6 inches of sub-base have been ranging from $20.40 to $23.80 per square yard in place, which is considerably higher than the $17.65 per square yard estimated based on PennDOT Bulletin 50 cost figures. Recent bid prices for pavement designs consisting of 1-1/2 inches of asphalt wearing surface, 2 inches of bituminous binder, 5 inches of ALP base, and a 6-inch sub-base have been ranging from $14.00 to $17.00 per square yard (Reference 5-5), which corresponds well with the estimated cost of $16.05 per square yard given above. The actual installed price for 5-inch thick ALP base in Lancaster during 1980 was $4.50 per square yard (Reference 5-6). All of the above costs are based on prevailing wage rates, making the costs for these projects equivalent to those of PennDOT projects.

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* In seeking to verify these unit prices from the latest Bulletin 50 (March 1980), it was discovered that no bid prices had been tabulated for several years. The value here was developed in cooperation with District 6 engineers.

On the basis of these costs, reflecting actual bids received during 1980 in the City of Lancaster, it would appear that even more substantial cost savings, on the order of \$5.00 to \$6.00 per square yard of pavement, can be realized by use of the pozzolanic base alternative. When analyzing the comparative costs of ALP and BCBC out of the plant, it is evident why ALP is the less costly alternative. Bituminous base in the Philadelphia area presently sells for approximately \$20.00 per ton F.O.B. plant, while ALP sells for \$9.50 per ton F.O.B. plant. In Pennsylvania, these two materials are structurally equivalent.

4. Three State Cost Comparison

The estimated costs for all three pavement alternates in Illinois, Ohio, and Pennsylvania for a flexible pavement with a structural number of 4.00 are compared in Table 5-6. These cost figures reflect actual bid costs for all materials and, as such, constitute an accurate current comparison of the cost of alternative pavement systems in each state.

The first and most obvious observation from Table 5-6 is that the pozzolanic base material is consistently the lowest cost alternative in all three states, with bituminous base second, and aggregate base third. The cost differential between pozzolanic base and bituminous base ranges from \$1.50 to \$3.00 per square yard. This difference represents potential cost savings of approximately \$20,000 to \$40,000 per mile of two-lane road.

A study of Table 5-6 also shows that total pavement costs in Illinois and Pennsylvania are basically quite similar, while comparative costs for the same materials in Ohio are somewhat lower, particularly the cost of the pozzolanic base. This simply points out the number of variables that must be taken into account when comparing cost figures for the same material from different areas. The most significant of these variables are labor, transportation costs, productivity at the project sites, and availability of materials. Despite these variables, the cost comparison discussed in this section of the report reflect a trend toward significant savings in cost from use of pozzolanic base materials in areas where such materials are available and can be supplied in sufficient quantity to prospective users.

In addition to the actual bid prices received in the three states, a theoretical calculation was made for 12 cities selected from all across the country. In each of those cities, current quoted prices were found for lime, fly ash, and aggregate. These costs were combined with an assumed value for manufacture and installation of LFA and bituminous base material and compared to an installed price for asphalt concrete. The result is in Table 5-7. As can be seen, LFA is less expensive in all cases.

Table 5-6

THREE-STATE COMPARISON OF PAVEMENT BASE COURSE COSTS

BASIC PAVEMENT DESIGNS

(Structural number = 4.0)

Illinois			Ohio			Pennsylvania		
BAM	PAM	STONE	BIT	POZ	STONE	BCBC	ALP	CABC
3" wearing 8.5" base 11.5" total	3" wearing 10" base 13" total	5" wearing 15.4" base 20.4" total	3" wearing 8.4" base 11.4" total	4" wearing 9.5" base 13.5" total	5" wearing 16.1" base 21.1" total	1.5" wearing 6" base 10" sub-base 17.5" total	1.5" wearing 2" binder 5" base 6" sub-base 14.5" total	1.5" wearing 2" binder 8" base 10" sub-base 21.5" total

COST COMPARISON

Illinois			Ohio			Pennsylvania		
BAM	PAM	STONE	BIT	POZ	STONE	BCBC	ALP	CABC
$ 4.64 12.87 $17.51	$ 4.64 10.87 $15.51 (Low)	$ 7.74 8.75 $16.49	$ 4.52 11.19 $15.71	$ 6.03 6.60 $12.63 (Low)	$ 7.53 9.08 $16.61	$ 3.30 10.20 4.15 $17.65	$ 3.30 3.00 6.00 3.75 $16.05 (Low)	$ 3.30 3.00 8.00 4.15 $18.45

Table 5-7

THEORETICAL STABILIZED BASE COURSE PRODUCTS, 1980
(Price per square yard)

	Lime-Fly Ash-Aggregate (9 inches)	Asphalt Concrete (6.7 inches)
Kansas City, Missouri	4.90	6.10
Atlanta, Georgia	5.46	7.80
Dallas, Texas	6.56	6.95
Chicago, Illinois	4.06	8.81
Phoeniz, Arizona	*	5.78
Philadelphia, Pennsylvania	4.10	7.80
Cleveland, Ohio	3.64	6.61
Baltimore, Maryland	3.97	8.13
Detroit, Michigan	3.64	6.10
St. Louis, Missouri	5.65	4.74
Pittsburgh, Pennsylvania	7.35	9.24
Washington, D.C.	4.22	7.80

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* Price not readily available in Phoenix at the time of the survey.

Because of the systematic lower cost of LFA, the question arises as to why LFA is not more widely used. There are a number of reasons for this. A primary reason is that the impressive price advantage has not existed long. It is a result of recent price increases in asphalt. Also, in some locations stabilized bases are not used, and more inexpensive aggregate bases can be used. Another reason is that the patents on LFA have just run out (in 1980), so that entering the LFA market was restricted to licensee in the past. Also, fly ash of sufficient volumes and quality has not been available in many places in the past. In addition, new road construction is being carried on at a greatly reduced level in many places, so that potential demand for LFA is quite limited at present. There is, however, significant new construction taking place as added lanes to existing roads. Finally, when these other problems do not exist, the institutional barriers are still there including the fact that routine use specifications do not exist in most places.

However, the impressive cost savings documented here will likely result in the solution to many of the problems listed here. There is little doubt that LFA in many places in this country can result in significant savings.

ENERGY AND ENVIRONMENTAL ANALYSIS

The potential energy and environmental effects of procurement guidelines need to be evaluated in terms of their total effect. Any mining, manufacturing, construction or transport activity results in energy consumption, pollution, and damage to the environment. The question to be answered is whether the procurement guidelines will result in more of these undesirable effects or less.

To do this, it is necessary to consider all of the activities related to the end result of interest. Thus, for LFA base courses, it includes not only the actual laying of the LFA, but also all of the preceding operations. As shown in Figure 5-6, this includes mining, transporting, and processing of minerals and aggregates; and procurement, processing, and transporting of fly ash as well. This must be compared to comparable operations for conventional materials.

The two most common bases used under flexible pavements are bituminous concrete (black base) and crushed stone (aggregate). To some extent portland cement stabilized bases are used, but they are more commonly used under rigid pavements and therefore frequently are not a viable alternative. Recently, recovered materials have been used in stabilized (or pozzolanic) bases. The most common application using recovered materials is a lime-fly ash-aggregate (LFA) base. However, other recovered materials can be used in LFA variations, such as boiler slag as a partial replacement for aggregate; cement or lime kiln dust as a replacement for lime; and incinerator residue as a partial replacement for aggregate.

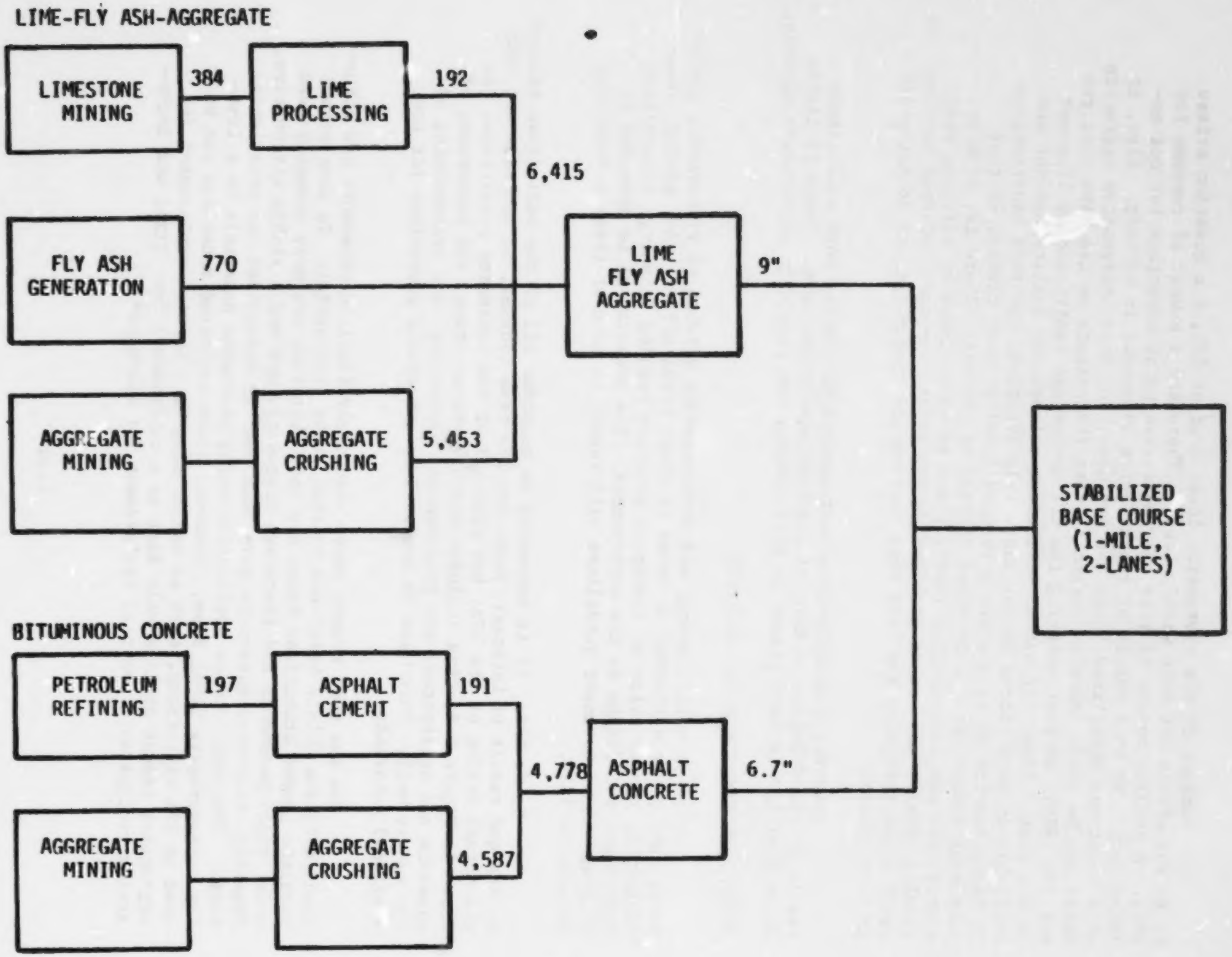
LIME-FLY ASH-AGGREGATE
LIMESTONE MINING
384
LIME PROCESSING
192
6,415
FLY ASH GENERATION
770
LIME FLY ASH AGGREGATE
9"
AGGREGATE MINING
AGGREGATE CRUSHING
5,453
STABILIZED BASE COURSE (1-MILE, 2-LANES)
BITUMINOUS CONCRETE
PETROLEUM REFINING
197
ASPHALT CEMENT
191
4,778
ASPHALT CONCRETE
6.7"
AGGREGATE MINING
AGGREGATE CRUSHING
4,587

Figure 5-6. Materials flow for lime-fly ash-aggregate or ashpalt concrete base course (tons).

For each of these options, a base of appropriate thickness was chosen for a typical pavement design, the details of which are in the Appendix. The energy and environmental calculations were made for the materials needed to lay one mile of 2-lane highway. For this comparison, LFA was the recovered material product chosen, and the comparison was to the virgin material which is functionally equivalent. Thus, a 9-inch thick LFA base was compared to asphalt concrete base 6.7 inches thick. The results are summarized in Table 5-8.

Table 5-8

STABILIZED BASE COURSE ALTERNATIVES
(One mile of 2-lane road)

	Lime-Fly Ash-Aggregate	Bituminous Base
Energy (10^9 Btu)	3.9	10.3
Air Pollution (10^3 lb)	123-160	58.7
Water Pollution (10^3 lb)	1.5	4.0
Processing Solid Waste (10^3 lb)	90.6	7.4
Materials Diverted from Waste (10^3 lb)	1,500	0

Source: Franklin Associates, Ltd.

The primary objective of the Resource Conservation and Recovery Act (RCRA) are: 1) to protect human health and the environment; and 2) to conserve valuable material and energy resources. These objectives are to be achieved by improving solid waste management practices.

Specifically, waste materials must be viewed as resources and reused to the maximum extent possible. Thus, one of the most important environmental aspects of use of LFA is the fact that 1.5 million pounds of fly ash is utilized for each mile of 2-lane road. Not only does this value translate to a potentially significant use of a waste material on a national basis, but it could be of even greater importance at the local level. Many coal-fired power plants are located in metropolitan areas where landfill space is scarce and quite expensive. Thus, the potential to use quite large amounts of fly ash may be quite important to an individual plant.

Another factor to be considered is that solid wastes are also generated by processing of highway construction materials. Every industrial activity generates some solid wastes as a result of its activities. For the comparison here, the LFA system generates more solid wastes than the asphalt concrete system. However, the 90,600 pounds of wastes generated are largely mineral wastes from lime processing. These are similar in terms of environmental impacts to fly ash. Hence, this processing waste is not a serious problem, but offsets to some degree the large waste disposal savings gained by using fly ash.

Energy

As can be seen from Table 5-8, LFA results in a significant energy savings, amounting to 6.4 billion Btu per mile. If 30 percent of the asphalt base used in 1978 were to be replaced by LFA, then use of 27 million tons of asphalt concrete in road base would be avoided. The use of LFA on this 5,700 miles of road would result in an energy savings of 0.04 quad of energy, or the equivalent of 7 million barrels of oil per year.

An important assumption made was that the energy content of the asphalt itself is included. Franklin Associates has determined by contacting petroleum refineries that asphalt cement is diluted and sold as a fuel oil if it is not sold as asphalt cement. Thus, its use in highway construction results in the removal of a fuel from the world's finite fossil energy inventory, just as if it had been burned. In terms of the impact on future energy supplies, there is no difference as to whether it is used as asphalt cement or as a fuel oil. This is an important assumption. Reference to Appendix A shows that if the fuel content of the asphalt is subtracted out, then the energy for the asphalt concrete option is 2.4×10^9 Btu. The energy for LFA is 3.9×10^9 Btu, so that under that assumption LFA would actually require more energy.

Air Pollution

All of the activities shown in Figure 5-6 produce some air pollution. However, Table 5-8 shows that LFA results in more air pollution than bituminous base. This is primarily because aggregate mining and crushing, and the handling of fly ash result in more particulate pollution than the asphalt concrete option.

Water Pollution

No significant water pollution is generated at manufacturing sites directly by the LFA system, but some water pollution is generated by the production of fuels used in the various steps. The primary source of water pollution is oil field brines associated with petroleum production. The same kinds of water pollutants are generated by the asphalt concrete system, but as shown in Table 5-8, the quantities are greater. However, the amounts generated are not large.

Another important water pollution problem related to materials in construction applications is leachate. Leachate production from "in place" products and composition are related to solubility, permeability, and chemical composition.

Generally, water penetration through the products studied is relatively low, as the permeability is quite low. This minimizes any potential leachate problems. The toxic substances contained in the materials can be determined by chemical analysis of the material itself, and are found to be primarily heavy metals. With respect to these toxic substances, the Environmental Protection Agency has established a guideline for Safe Drinking Water Standards. A concern exists if the extract from the material (obtained by a testing means such as the EP toxicity test method) has a concentration of any constituent greater than one hundred times the established water standard.

As a part of this research project, a limited number of samples were obtained from existing roads and embankments in which power plant ash had been utilized. These samples were subjected to leachate extraction procedures, with the leachate being subsequently evaluated by standard laboratory procedures. The procedures used were in accordance with EPA recommendations.

Included in Appendix E, Volume 2, is a description of the method used in the leaching tests, the Federal Register notice describing the "EP Toxicity Test," and a summary of the results.

Although the number of tests performed was not of sufficient magnitude to extrapolate the results to all highway construction products containing recovered materials, the tests do not indicate that there is an environmental hazard. As far as is known, there are no known leachate extraction test results from field highway construction samples that do indicate any significant toxic leachate associated with this kind of use.

Summary

It would appear that the use of LFA produces potentially significant solid waste and energy benefits when compared to asphalt concrete. However, the dust problem created by minerals handling may cause some adverse impact in terms of air quality. Water pollution is not significant, and the processing wastes generated are not important in view of the considerable alleviation of solid waste resulting from the use of fly ash.

GUIDELINE OPTIONS

Introduction

There is a broad range of guideline options available to EPA. The two extreme options would theoretically be no guidelines at all, or mandatory guidelines that would require fixed minimum amounts of recovered materials. These two theoretical extremes are discussed in Chapter 3. Between these two extremes are a number of more plausible options which are presented and analyzed in this section.

In the material which follows, a brief summary of the conclusions reached in this chapter is presented, followed by an analysis of five guideline options. Those options are: 1) dual bids; 2) dual bids applicable to selected states; 3) increase and improve educational activities; 4) use of grants, bonuses, or other financial incentives; and 5) phased in, or delay of guidline implementation. Advantages and disadvantages of each option are presented, but no option is singled out for recommendation by the authors. EPA options also include using a combination of the five options discussed.

Conclusions

The primary conclusion based on the preceding analysis is that LFA has had a long history of successful use as a stabilized road base material, and has been proven effective in all geographical areas of the country. It is also clear that even though it possesses clear advantages and in many areas it costs less than asphalt cement base material, its use is far from commonplace. No single reason seems to exist for the lack of use of LFA, but several reasons can be cited. One important reason is the natural conservatism of the highway construction industry, as discussed in Chapter 4. This has been compounded by the fact that until 1980, LFA was patented, and considered by many highway engineers as a proprietary product. There is a certain aversion in many states to become dependent on a proprietary product. Another factor is that intense lobbying efforts by entrenched materials producers is sometimes effective, and this undoubtedly had some effect on the slowness of some states to examine LFA extensively. Also, the economic attractiveness which is important to overcoming these other factors has been developing only in the past few years, and is not yet widely appreciated.

Since the technology for use of LFA materials has been well established over many years, and its use is considered highly beneficial technically, economically, and environmentally, increased utilization of fly ash in LFA compositions is warranted. Because of sluggish acceptance of this material over the years in many potential use areas, a more vigorous promotional effort is needed.

Any promotional effort on behalf of LFA materials should emphasize the following points to users or prospective users:

1. LFA materials make use of well-graded aggregates, not sand or other soils.
2. The product must be plant mixed to assure needed quality control.
3. Proper moisture content and compactive effort are absolutely critical to the successful performance of the product.
4. Fly ash used in LFA mixtures does not necessitate the same rigid quality requirements as fly ash used in portland cement concrete.
5. Late season construction cutoff dates must be a consideration, especially in northern states.
6. Use of LFA materials saves money and energy.

In the implementation of more widespread use of LFA materials at the state level, several steps are necessary. The number of steps will depend on the experience a given state has had with LFA materials. These steps are:

1. Evaluation of LFA materials in the laboratory.
2. Preparation of specifications for LFA materials.
3. Demonstration of LFA materials in the field.
4. Accepting bids for placing LFA materials on state highway projects.

It is important to incorporate these steps into any implementation process, not only so that state engineers can become more familiar with the product, but also, in many cases, so that producers and contractors may also gain needed experience in production and placement of LFA materials.

Another consideration is that there are at present a limited number of producers of LFA materials. Production facilities are not located in every one of the 34 potential use states listed in Table 5-4. Even in states where LFA is now used, only certain portions of these states are presently served by existing LFA production plants. An investment of money and time are needed to prepare an existing blacktop plant for production of LFA base materials. Therefore, some time delay will be needed to allow the market to make appropriate adjustments and let supply and demand take effect.

Dual Bids

One guideline option available to EPA is to require dual bids when a stabilized base course is required. That is, LFA must be specified as one possible base course material. Exceptions would have to be allowed such as when there are time constraints so that the base will be installed outside of the LFA construction season; or that the road must have heavy traffic on it too soon for the LFA to cure adequately. In other cases, however, the procuring agency would be required to allow LFA as a material should a contractor desire to place a bid. For example, a procuring agency might specify that either an asphalt concrete base of a certain thickness, or an LFA base of a certain thickness, could be proposed by a bidder.

This dual bid would take one of several forms depending on state laws. In some states, the appropriate form would be as an alternate bid. When this mechanism is used, the bid document instructs the bidder that their bid must be for either LFA or for the conventional material. Thus, the choice of material is fixed at the time of contract award, and the winning contractor uses the material that he chose when preparing his bid.

In some states the mechanism used is an optional approach. In that form, the contract is awarded before the material choice is made. That is, the job is bid at a certain price, and the contractor agrees to select one of the optional materials at a later time. Then, when construction begins, the contractor exercises his option to decide which material will be used, which usually is the material which results in the least cost to him at that time. However, some provision would need to be made for states which do not have specifications for routine use. In some states where tests have already been made and evaluated, this may only require a year. However, in states where tests are not completed it may require as many as five years. At present, only one state has specifications for routine use--Pennsylvania--so most states would require additional time. However, five other states have supplemental specifications which could be used immediately, and standard specifications for the state could be developed quickly.

Advantages. The advantages of the dual approach is that recovered material use is encouraged, but not required. If a contractor wants to use LFA and feels that he can be low bidder by so doing, this opportunity is available to him. The dual bid approach is a strong approach in that it requires procuring agencies not experienced in the use of LFA to become knowledgeable about that material and to specify which applications are most suitable. It insures that competition will be maximized by allowing contractors to bid conventional materials or LFA. Thus, no potential contractors are excluded from the competition because of a material requirement. This procedure also insures that the material will be readily available, because contractors will not bid a material for which this uncertainty exists. Finally, the dual bid approach insures that products are purchased at the least cost to the procuring agency because of the competitive bid situation.

Disadvantages. One problem with dual bids is that it will not be successful in stimulating use of LFA where procuring agencies do not believe it is an acceptable material. The dual bid procedure can be easily circumvented by writing some provision into the specification that will insure that LFA would never be cost competitive. Perhaps the easiest way to do this would be to assign LFA a low structural number, so that a fairly thick layer of LFA would be required. This could insure that LFA would never win a competitive bid. These acts by a procuring agency may be based on a covert attempt to avoid use of a material, but are difficult to identify and correct, because experimental data may be cited which support their position. The extremely wide variations in composition and quality of construction materials available in a given place, along with extreme variations in climate, soils, and other environmental conditions, make independent judgment of design specifications difficult. However, sufficient field experience with LFA now exists so that the guidelines could disallow any specifications that would require LFA to be more than 25 percent thicker than the comparable asphalt concrete base.

Dual bids may also cause an inconvenience in many locations where LFA does not ever win bids. In some locations, fly ash is not available locally and may be quite expensive to import. In some locations asphalt concrete is quite inexpensive, and in those areas LFA may never be the low bid. Thus, any rule requiring dual bids would result in unnecessary work for the procuring agency. In many states, dual bids result in the necessity of preparing separate designs for each material. In some states this is a minor problem. In others it is considered a major problem. In any event, if LFA never wins bids, any extra effort to prepare a dual bid would be considered as wasted effort by the procuring agency.

Also, because almost all states do not presently have a specification for routine use of LFA, this guideline option would have to have a delayed implementation. However, some states would be able to prepare specifications in less than one year because of previous experience, and most states could adopt a temporary or supplemental specification. Thus, one to two years should be sufficient.

Dual Bids Applicable to Selected States

Fly ash is much more readily available in some states than in others. Also, fly ash is a more serious waste problem in some states. The most severe waste problem is in the seven states that produce more than 3 million tons of fly ash annually. Those states are Illinois, Indiana, Kentucky, Michigan, Ohio, Pennsylvania, and West Virginia. These seven states account for one-half of the nation's fly ash generation. Also, as shown in Figure 5-4, page 5-25, these are states in which lime plants are in reasonable proximity of power plants, which enhances the probability that LFA would be available. A guideline for dual bids could apply only to those seven states where the fly ash waste problem is most severe and the probability of availability of LFA is high. Alternatively, some other selection process could be used to identify selected states to which the guidelines would apply.

Advantages. As can be seen from the data presented on pages 5-6 to 5-9, most states west of the Mississippi River, and the New England states, do not have a widespread problem of fly ash wastes (although some severe local problems may exist). In the rural areas, particularly in the west, many power plants are located where land disposal is readily available. Thus, those states do not perceive that fly ash is a serious problem. A primary advantage of this guideline is that it does not cause a paperwork burden in areas where a problem is not perceived, and the lack of availability of LFA would preclude its widespread use.

In addition, for the states selected, LFA would likely be available in most of the state. If the other states are included, roads would be built in many regions of the state which are remote from power plants and lime plants. Thus, the dual bids procedure would work most efficiently in states where LFA is widely available.

Disadvantages. A selective guideline procedure will not maximize the use of fly ash. For the seven-state region suggested, only one-half of the fly ash produced is included. Thus the guideline will not achieve maximum effectiveness in terms of fly ash use. In fact, as can be seen from Figure 5-3, page 5-18, there are areas in other states, or areas which include portions of states, which are difficult to define, but which could provide the raw materials for LFA. These would be omitted from the suggested selection procedure.

Another problem is the basis of selection of the states. What is needed is an analytical selection process based on a reliable statistical measure. The statistics cited for this selection are estimated, and the 3 million tons per year of fly ash production cut-off was chosen arbitrarily. Thus, selected states could appeal their selection by claiming that the process was arbitrary and capricious.

Increase and Improve Educational Activities

A guideline requiring dual bids places requirements on direct Federal procurements, and to a much greater extent places a requirement on state and local highway construction procuring agencies. An alternate to this approach is to put more of the responsibility on the Federal government. One way of doing this is to require that the Federal Highway Administration (FHWA) increase and improve their educational activities. It is clear that at the headquarter level in Washington, D.C., FHWA has done much to promote and encourage the use of LFA by preparing and disseminating educational materials (such as a slide-sound presentation on LFA base) to the FHWA regional offices. However, from the interviews with the states, it is clear that most district level FHWA engineers have not promoted the use of LFA. Thus, the focus of this activity would be to insure that FHWA district engineers in every state are well trained in the use and new developments of LFA base materials. In turn, they should make state departments of transportation officials aware of the importance of use of LFA as a national policy and of the importance for each state to seriously study the potential advantages of use of LFA within the state. Dissemination of information and conducting training sessions for state district engineers should be encouraged. Perhaps key states, such as the seven states mentioned previously, could be targeted for this activity initially.

FHWA has recently increased activity in this area. Thus, EPA should remain current on the present status before implementing guidelines.

Advantages. An advantage of this guideline is that it does not force the use of LFA or even of dual designs and therefore will insure that its use can be carefully evaluated by each procuring agency. It would be a wise approach from the point of being less "heavy handed" with regard to the states by not placing requirements for dual bids on them. However, it should increase the awareness of LFA and would likely result in more use.

Disadvantages. A disadvantage of this guideline option is that it may result in less immediate use of LFA than a dual bid guideline. Also, it will require expenditures on the part of FHWA to provide a staff to implement this activity. Because of a generally tight budget situation, this may cause some difficulty for that agency.

Another disadvantage is that in some cases district engineers will ignore these guidelines to the extent possible; in other cases, they may be overzealous and place undue pressure on states to use recovered materials to the extent that they would be used in inappropriate or uneconomical applications. Either of these types of actions would be contrary to the intent of the guidelines.

Increase Funding for Research and Testing

After over 20 years of extensive field work and testing, the basic nature of LFA is well understood, and its applications can be readily identified by those knowledgeable about the material. However, sufficient tests have not been performed by many states. Thus, FHWA could make money available to states for additional research and testing of LFA. In fact, FHWA plans to embark on a demonstration program for uses of fly ash in highway construction, including lime-fly ash-aggregate base course compositions.

Advantages. An advantage of this guideline is that it would decrease the time until LFA could be included in state specifications. This would increase the ability to incorporate LFA in road construction and to increase the reliability of installation. This would enhance its salability and lead to wider use.

Disadvantages. The main disadvantage would be that FHWA would likely have to divert research funds from other projects which they have identified as being more important. Thus, a basic policy decision would need to be made that it is more important for FHWA to conduct research alleviating the solid waste problem than to fund additional research for LFA solely on its merit as a highway construction material. FHWA has already made its judgment with regard to the merits of LFA based on research that has already been done, and this guideline would essentially require them to alter those decisions in favor of funding more research on LFA.

An alternative may be additional funding by Congress for these activities. If use of recovered materials is deemed to be in the national interest, this would be justification for increasing the FHWA budget in order to fund these activities.

Another disadvantage of this guideline is that the payoff might be low. The problems with LFA are already well understood and readily solved. Thus, additional funding for research in this area may in many ways repeat previous work.

Use of Grants, Bonuses, or Other Financial Incentives

A way to encourage procuring agencies to use more LFA is to use financial incentives. This could take many forms. It could include block grants to states to use LFA, or to experiment with its use. Another option would be to grant a bonus on projects using LFA. For example, if the normal Federal share of a particular road were 70 percent, a state could be granted a bonus to use LFA on the roadway and receive a greater Federal share, say another 5 percent to 75 percent for the portion of the project where LFA was used.

Perhaps this program could be implemented as an extension of current FHWA demonstration programs, where financial incentives are offered to states for first time installation of demonstration or test sections.

Advantages. This would be one of the most rapid ways in which to increase the use of LFA. A serious problem facing virtually all highway construction entities is a shortage of funds. Providing money for road-building and maintenance in any form would be met with a more positive response than any other option. However, at present FHWA does not ordinarily provide any funds for maintenance activities.

Disadvantages. The most serious disadvantage to this guideline would be the locating of funds. FHWA administers the Federal funding of highway construction projects, and they are suffering a severe erosion of funds which can be used for highway construction. Therefore, a basic policy decision would have to be made that money could be diverted from other uses for the purpose of funding these guideline options. However, as discussed previously, an alternative would be for Congress to increase funding levels because use of recovered materials is deemed to be in the national interest.

Another major disadvantage is that the economics of LFA already stimulate its use. Many projects would receive additional funding that would be unnecessary because LFA would be used anyway.

Another potential problem with this guideline option is that it is possible that the legal restrictions on ways in which money is disbursed would not permit certain kinds of financial incentives. These would have to be carefully investigated. It is possible that additional legislation would be required to allow use of funds in this way.

Delay Guideline Implementation

A final guideline option is to delay implementation of a specific guideline option for a specified number of years. For example, EPA could publish their intent to implement a dual bid guideline in 2 to 4 years.

Advantages. In 2 to 4 years, hundreds of installations that have been placed will have been more completely evaluated, and the picture on how and where LFA should be used will be clearer. In addition, a formal notice by EPA of the intent to implement a guideline for LFA would give procuring agencies time to develop specifications and to plan for the best use of the material and how best to comply with the guidelines.

Disadvantages. The primary disadvantage of this option is that it would delay any definitive action by EPA and thus postpone any possible benefits of a guideline.

Chapter 5

REFERENCES

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Chapter 6

USE OF KILN DUSTS IN HIGHWAY CONSTRUCTION PRODUCTS

INTROUDCTION TO KILN DUSTS

As air pollution control activity has increased, so has the amount of solid waste products collected by pollution control devices. In some cases, the wastes consist of product dusts which have been lost from the processing operations, and previously were dispersed in the atmosphere. Now, however, they are collected and are readily usable in some cases. In this study, cement kiln dusts have been identified as potentially significant for use in highway construction products.

TECHNICAL DESCRIPTION OF KILN DUST GENERATION AND RECOVERY

Cement Kiln Dust

The manufacturing of portland cement involves five basic steps: quarrying, raw grinding, blending, burning, and finish grinding. The raw materials for portland cement consist of materials containing four particular compounds: lime, silica, alumina, and iron oxide. The more commonly used materials are various combinations of limestone, shale, clay, sand, oyster shell, cement rock, marl, iron ore, and various byproduct materials including ash, slag, and tailings from several mineral processing industries. These materials are proportioned as necessary to form a suitable raw mix and ground together either as a dry mixture or as a water slurry. At this stage, most of the material is 200 mesh or finer and after blending is ready for introduction to the kiln.

Kilns for producing portland cement are large, rotating, inclined metal tubes, usually 8 to 15 feet in diameter and 200 to 500 feet in length. At the lower end of the kiln is a burner, fired by gas, oil, or coal, that produces a 3,300°F flame. Raw materials enter the upper end of the kiln and move down the kiln toward the burner as the kiln rotates. As the mix traverses the kiln, its temperature increases and three things happen. Moisture is driven off, calcium carbonate decomposes to calcium oxide (lime), and the mass reaches a temperature of incipient fusion, about 2,700°F, at which hard, marble-sized balls called clinker are formed. The clinker is discharged from the kiln, cooled, and ground into portland cement, with a fineness of about 325 mesh. During this process about 3,400 pounds of raw materials have been transformed into one ton of portland cement, and 3 to 5 million Btu of energy have been consumed.

Cement kiln dust (CKD) is the dust collected from the exhaust gases of cement kilns. Kiln dust originates when finely ground raw materials become airborne in the stream of combustion gases traveling up the kiln. Carbon dioxide, liberated by the decomposition of calcium carbonate, adds to the agitation of the materials and thus to the amount of airborne dust. The dust is a mixture of kiln raw materials which have been partially processed, finely divided cement clinker and alkali chemicals (usually sulfates).

Its chemical composition is variable but usually consists of calcium (or magnesium) oxide (lime), silicon dioxide (sand), with small amounts of compounds of aluminum, iron, magnesium, sodium, and potasium. It is a fine granular material similar in appearance to cement.

Mechanical collectors (cyclones), glass-bag filters (baghouses), and electrostatic precipitators are commonly used to collect kiln dust. Because they are relatively inexpensive and maintenance free, cyclones are often used ahead of baghouses or precipitators to collect the larger dust particles, but the cyclones cannot be used alone because their efficiency for collecting particles less than 10 microns is low. High collection efficiencies, approaching 100 percent, can be achieved with baghouses and precipitators.

Lime Kiln Dust

Lime is produced in operations which bear some similarity to cement manufacture, but are simpler. Limestone is quarried and ground, and then introduced to vertical or rotary kilns. The rotary kilns are quite large, generally being 150 feet or longer. Almost no dust is produced in vertical kilns, so subsequent discussions relate to rotary kilns.

The ground limestone is frequently mixed with coal, in the proportion of about 3-1/3 pounds of limestone to one pound of coal. The coal is combusted as the limestone-coal mixture works its way along the kiln. When the limestone reaches a temperature of about 1,600°F, it begins to decompose. Limestone is calcium (or magnesium) carbonate, but it decomposes into calcium (or magnesium) oxide (which is lime) and carbon dioxide. The gases from the combustion of coal, the liberated carbon dioxide, and the excess air associated with combustion, generate a considerable draft in the kiln which picks up dust. The dust is collected in air pollution control devices which are essentially the same as those described for CKD.

The dust collected contains a mixture of partially processed raw material (limestone) and lime. The chemical compositions of LKD are highly variable, but are primarily calcium oxide (lime), calcium carbonate (limestone), with some silicon dioxide (sand) which is an impurity in the raw material. LKD is a quite fine dust, and is similar in appearance to CKD.

QUANTITIES OF KILN DUSTS GENERATED

At the present time it is estimated that the annual production of lime and cement kiln dusts is in the range of 10 to 14 million tons. The solid waste problem is large enough to be of national concern. In physical dimensions, 12 million tons would occupy a volume of 250 million cubic feet. Thus, the volume of kiln dusts would fill approximately 10 professional football stadiums each year.

Most of this waste is CKD. Although statistics are not available, current estimates are that 20 million tons of CKD are produced annually, with 8 million tons recycled internally. Thus, 10 to 12 million tons of CKD are presently being accumulated annually (References 6-1, 6-2, and 6-3).* In addition, it is estimated there are 100 million tons of the material that are reusable piled throughout the country.

The annual accumulation of LKD is considerably less than that of CKD. In a 1977 survey conducted by the National Lime Association (Reference 6-4), in which 60 out of 75 commercial lime plants responded, a reported 4,275 tons per day of dust were collected. It was estimated that this was two-thirds dry dust and one-third sludge. Of this amount, approximately 75 percent was wasted and 25 percent either sold or given away. If these data are factored up for 330 working days per year, for a 50 percent addition to adjust for captive lime plants, and for the non-reporting plants in the survey, the available annual output can be estimated as 1.3 million tons per year. Other sources suggest that this is approximately correct, although the value may be as high as 1.5 million tons per year.

Geographical Generation Patterns

As shown in Tables 6-1 and Figures 6-1 and 6-2, the latest available information on the location of cement plants shows 168 plants distributed throughout 39 states. Over half of these plants are located in eight states. In addition, the geographical distribution of the plants within these states indicates that CKD would be available within reasonable transportation distance at most locations. These states are: Alabama, California, Indiana, Michigan, Ohio, Pennsylvania, Tennessee, and Texas. Three other states have a significant number of cement plants but they are more or less concentrated in one section of the state. These states are as follows:

Kansas - plants are in the eastern portion of the state
Missouri - plants are in the eastern portion of the state
New York - plants are in the southeastern portion of the state.

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* See references at the end of the chapter.

Table 6-1

ESTIMATED ANNUAL GENERATION OF KILN DUST BY STATE

	Cement		Lime[1]		
	No. of Plants	Dust (10^3 tons)	No. of Plants	No. of Rotary Kilns	Dust (10^3 tons)
EPA Region 1					
Massachusetts	0	0	2	1	14
New Hampshire	0	0	0	0	0
Connecticut	0	0	1	1	4
Maine	1	75	0	0	0
Rhode Island	0	0	0	0	0
Vermont	0	0	0	0	0
Total	1	75	3	2	18
EPA Region 2					
New York	7	674	0	0	0
New Jersey	0	0	1	1	150
Total	7	674	1	1	150
EPA Region 3					
Pennsylvania	15	1,232	7	6	215
Maryland	3	256	0	0	0
West Virginia	1	128	2	1	25
Virginia	1	111	5	4	76
District of Columbia	0	0	0	0	0
Delaware	0	0	0	0	0
Total	20	1,727	14	11	316
EPA Region 4					
Kentucky	1	70	2	2	50
Tennessee	6	304	0	0	0
North Carolina	1	111	0	0	0
South Carolina	3	335	0	0	0
Mississippi	2	192	0	0	0
Alabama	7	470	5	5	143
Georgia	3	238	0	0	0
Florida	5	508	0	0	0
Total	28	2,228	7	7	193
EPA Region 5					
Minnesota	0	0	0	0	0
Wisconsin	1	140	5	3	22
Michigan	5	1,116	3	2	133
Illinois	4	365	3	3	240
Indiana	5	240	1	1	80
Ohio	5	394	12	8	336
Total	20	2,255	24	17	811

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[1] Quantities of lime kiln dust represent estimated dust production from commercial lime plants. No similar data were available on dust generation from 65 captive lime plants at the time of this survey.

Table 6-1 (continued)

ESTIMATED ANNUAL GENERATION OF KILN DUST BY STATE

	Cement		Lime 1/		
	No. of Plants	Dust (10^3 tons)	No. of Plants	No. of Rotary Kilns	Dust (10^3 tons)
EPA Region 6					
Texas	31	1,694	7	6	138
New Mexico	1	100	1	1	16
Oklahoma	3	344	1	1	16
Arkansas	2	229	1	0	0
Louisiana	2	128	2	2	33
Total	39	2,495	12	10	203
EPA Region 7					
Kansas	5	404	0	0	0
Missouri	7	931	3	2	85
Iowa	5	529	1	1	21
Nebraska	2	186	0	0	0
Total	19	2,050	4	3	106
EPA Region 8					
Montana	2	114	0	0	0
North Dakota	0	0	0	0	0
South Dakota	1	93	0	0	0
Wyoming	1	57	0	0	0
Utah	2	200	0	0	0
Colorado	3	300	0	0	0
Total	9	764	0	0	0
EPA Region 9					
California	12	1,854	3	2	36
Nevada	1	58	3	3	54
Arizona	2	200	2	2	71
Hawaii	1	69	0	0	0
Total	16	2,181	8	7	161
EPA Region 10					
Washington	4	292	0	0	0
Oregon	2	116	0	0	0
Idaho	1	57	0	0	0
Alaska	0	0	0	0	0
Total	7	465	0	0	0
Total United States	166	14,914	73	58	1,958

1/ Quantities of lime kiln dust represent estimated dust production from commercial lime plants. No similar data were available on dust generation from 65 captive lime plants at the time of this survey.

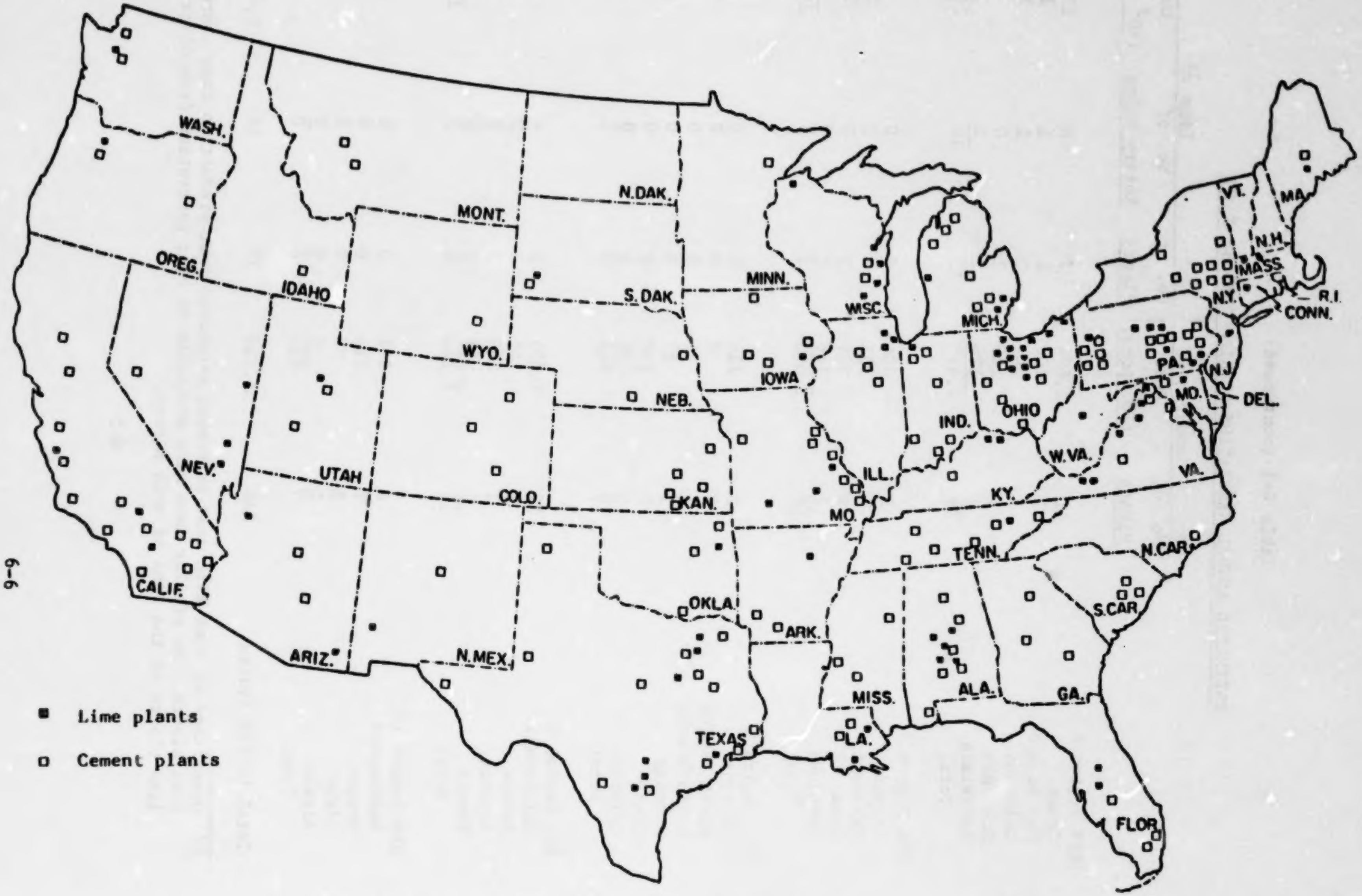
WASH.
OREG.
CALIF.
NEV.
IDAHO
MONT.
WYO.
UTAH
ARIZ.
COLO.
N.MEX.
N.DAK.
S.DAK.
NEB.
KAN.
OKLA.
TEXAS
MINN.
IOWA
MO.
ARK.
LA.
WISC.
ILL.
MISS.
MICH.
IND.
KY.
TENN.
ALA.
OHIO
W.VA.
GA.
FLOR.
VA.
N.CAR.
S.CAR.
PA.
MD.
DEL.
N.J.
N.Y.
CONN.
R.I.
MASS.
VT.
N.H.
MA.
Lime plants
Cement plants

Figure 6-1. Location of cement and lime plants.

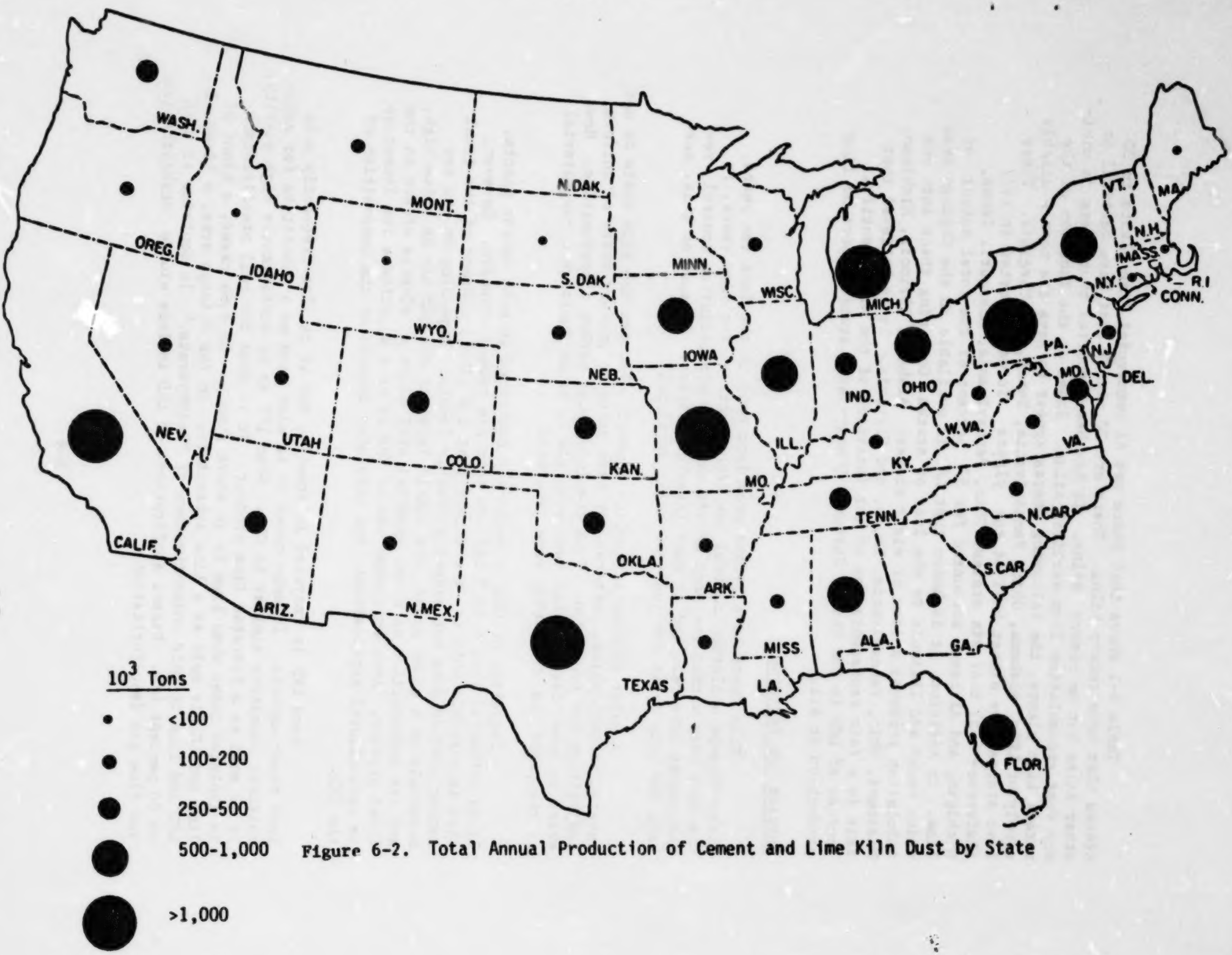
WASH.
OREG.
CALIF.
NEV.
IDAHO
MONT.
WYO.
UTAH
ARIZ.
COLO.
N.MEX.
N.DAK.
S.DAK.
NEB.
KAN.
OKLA.
TEXAS
MINN.
IOWA
MO.
ARK.
LA.
WISC.
ILL.
MISS.
MICH.
IND.
KY.
TENN.
ALA.
OHIO
W.VA.
GA.
FLOR.
S.CAR.
N.CAR.
VA.
MD.
DEL.
PA.
N.J.
N.Y.
CONN.
R.I.
MASS.
N.H.
VT.
MA.
10^3 Tons
<100
100-200
250-500
500-1,000
>1,000

Figure 6-2. Total Annual Production of Cement and Lime Kiln Dust by State

Table 6-1 shows that there are 61 commercial lime plants in 30 states that have rotary kilns. There are 20 plants that have vertical or other kilns but no rotary kilns. It has been reported that there is minimum dust accumulation from vertical kilns. Based on the location of the rotary kiln plants, the following states appear to have the most available supply of LKD: Alabama, Ohio, Pennsylvania, Texas, and Virginia. These five states have almost half of the plants. It was reported in 1977 (Reference 6-5) that six states, Ohio, Pennsylvania, Missouri, Texas, Michigan, and Alabama, accounted for 57 percent of the total output of lime. In addition, it is known that LKD is available in the Chicago area which would add Illinois to the list of states. Combining these into one tabulation produces a list of eight states: Alabama, Illinois, Michigan, Missouri, Ohio, Pennsylvania, Texas, and Virginia. It is believed that this is a fair representation of the locations of the most plentiful sources of LKD in the United States. Twenty-seven states report no lime production at all.

Current Use Patterns

Kiln dusts have become prevalent only in the last ten years. Although some pollution control has been practiced for many years, it has only been within the past decade that new air pollution control requirements have resulted in such large quantities. Because of this, markets for kiln dusts are just now being developed.

A major problem is quality control. Because the kiln dusts do not have sufficient value, care has not been taken to produce dusts of uniform composition and condition. This precludes most market opportunities. However, in some cases it has been possible to reuse dusts as a raw material in the plant in which they were generated.

Recycling of CKD is routinely practiced in many cement plants. It is estimated that 6 to 8 million tons are reused annually. However, this is possible only to the extent that the alkali content of the final cement product does not exceed allowable levels. Depending on the raw materials at a given plant, the alkali level in the CKD may be quite high, and its introduction as a raw material will cause an adverse effect on the final product. Another common use of CKD is as a substitute for limestone in agricultural applications, but this also depends on the composition of the CKD.

Some LKD is recycled internally, but it is also frequently sold into other markets. In some cases it is also used as a substitute for agricultural limestone similar to CKD. When LKD is of sufficiently high quality, it is sold as a hydrated lime product. It is used for soil stabilization in isolated cases when lime is in short supply. In some cases, a blend of lime and LKD is sold as a lime substitute. In the Chicago area, a blend of LKD and lime is sold under the name of "Polyhydrate." It contains as much as 80 percent LKD. Recent applications of LKD include sludge stabilization and flue gas desulfurization.

KILN DUST PRODUCTS

Description

The primary application of both kiln dusts would be as a replacement (or source) for the lime in lime-pozzolan-aggregate road base compositions. CKD can also be used in combination with fly ash or by itself to produce a stabilized composition for use as a road base or structural fill. One other application in highway construction is the use of LKD as an antistripping agent and/or filler in bituminous compositions.

Kiln dusts have additional potential in any highway application for which hydrated lime is used. This would include soil stabilization, combination with sulfate wastes to form stabilized base material, and treatment of wet, plastic subgrades. Although the use of kiln dusts in these applications has been largely unproven, it is anticipated that it will provide a similar product to that where the usual hydrated lime is used.

Dusts provide a considerable advantage over the use of lime, in that they are produced as a waste product, and therefore are lower in cost than lime. Then, dusts can be used in areas where use of lime is not feasible because the transportation costs would make the cost of lime prohibitive. Also, it has been reported that lime is frequently not readily available for highway projects, because production of lime from many plants is substantially committed to other customers. In these cases, the kiln dusts make it possible to extend lime supplies.

Commercial Availability of Products Containing Kiln Dust

The primary product discussed here is the use of CKD or LKD as a replacement for lime in lime-fly ash-aggregate stabilized base materials. At the present time this product is not commercially available in most parts of the country. It is patented and licenses are currently being made available to manufacture and install this product. Thus, at this time the lack of commercial availability would create serious problems for a guideline which would be written to encourage widespread use. However, it is possible that this product will be widely available soon.

Quality Control

A major disadvantage to the use of dusts is the extreme difficulty of obtaining adequate quality control. Changes in raw materials at the cement and lime plants, changes in daily operating parameters, and plant upsets change the chemical composition and physical characteristics of the dust. Testing of dusts from many plants has been done, and in many cases the dust is simply not usable. However, as the dust becomes viewed more as a coproduct of the plant, this situation will improve, and usable dust will be available from many plants. Nevertheless, because of differing raw materials used in cement plants, some will never produce a dust with a chemical composition that is satisfactory.

In the case of fly ash, an important factor which has increased the quality control is the presence of brokers and marketers of the fly ash. Because this is their primary business interest, they take frequent samples and work closely with plant production people. They can guarantee quality fly ash to a customer. This same system is now developing for kiln dusts, so the problem of quality control is being rapidly reduced.

Locations of Producers

Only three companies have been engaged in the past in providing kiln dust-fly ash-aggregate compositions for field installations. These companies are:

- Nicholson Industries, Toledo, Ohio
- Gallagher Asphalt Co., Chicago, Illinois
- City Wide Asphalt Co., Sugar Creek, Missouri

These are the only organizations which would be capable of supplying the material now to local clients. Although the commercial availability is quite limited at present, it is reported that this list is rapidly expanding.

While there are only a few plants that have had experience with kiln dust road base compositions, there are many that could supply the material in a relatively short period of time. These potential suppliers fall into two categories. The first category are those who have in the past or are currently engaged in supplying lime-pozzolan-aggregate base course materials. It would be necessary only to replace the hydrated lime in one of the storage bins with kiln dust and possibly recalibrate the feed system for the new mixture. The second category are those mixing plants that normally supply bituminous mixtures and/or portland cement concrete. With some addition of bins and conveyors, it is conceivable that any of these plants could readiliy (within a matter of months) be fitted to produce "pozzolanic concrete" using kiln dusts.

In addition to these possibilities, it has been estimated that a new plant could be put into operation within approximately 9 months--assuming there would be no excessive delay in obtaining the required equipment. The plants are not very sophisticated to assemble or to operate.

The availability of producers is not considered to be a deterrent to the expanded use of kiln dust.

Current Use Patterns

At the present time only five field tests have been installed with no large commercial applications to date. These test installations are described in detail beginning on page 6-13. Thus, no significant use pattern exists at this time.

Potential Use

The potential for use of kiln dusts is as a replacement for lime in lime-fly ash-aggregate (LFA) material is of course dependent on the use of LFA, and the availability of kiln dusts in proximity of LFA applications. It is estimated that 738,000 tons of LFA were produced in 1979. If kiln dust is used at the rate of 8 percent of the final material, a total replacement of the lime would have resulted in 59,000 tons of kiln dust being used. This is on the order of one-half of one percent of the kiln dusts disposed of in 1979, and therefore would be an insignificant use of waste on a national scale.

Because LFA has not yet achieved much more than moderate use, any calculations of potential use are little more than quite rough estimates. However, in order to determine if use of kiln dusts might even remotely be of importance, a ballpark calculation can be made. LFA can be considered as primarily a replacement for hot-mix asphalt base. In those applications, it can be assumed that 1.3 tons will functionally replace 1.0 tons of asphalt base. If LFA utilizes 8 percent kiln dusts, then, 0.10 ton of kiln dusts will be used for each ton of asphalt base replaced.

In 1978, 90 million tons of asphalt base were used. Kiln dusts are available in only about 75 percent of the states, so as a rough estimate 68 million tons of black base could theoretically even be a candidate for replacement. In the next decade, it is unlikely that kiln dusts could be utilized in replacements for more than 10 percent of this amount, or 6.8 million tons of black base. This would be a use of kiln dust of only 0.68 million tons, or only 6 percent of the kiln dusts solid waste problem in the country.

These estimates are admittedly quite rough, but they do show the potential for small but significant use of a waste material which is of national concern.

TECHNICAL ASSESSMENT

Field experience with kiln dust compositions is limited. Details on experimental road bases that have been in service for as much as four years are presented later in this report. Laboratory studies, however, are of much more significance than they ordinarily would be because of the close similarity to lime-fly ash-aggregate compositions which have a long history of performance. In addition, it is important to note that the compositions can be improved by small additions of portland cement.

More technical details concerning this discussion can be found in Part 2, Volume 2, where supporting data and discussion may be found.

Laboratory Investigation - Cement Kiln Dust

Compressive Strength and Density. The laboratory investigations of compressive strength were made in accordance with generally accepted standards for the evaluation of compositions of this nature. Much of the testing was done in accordance with ASTM C593, Fly Ash and Other Pozzolans for Use with Lime.

The observations show that the compressive strength and density characteristics of cement kiln dust, fly ash, aggregate compositions are typical for stabilized materials. In particular, they closely resemble results that would be obtained with lime, pozzolan, aggregate compositions. Secondary compressive strengths in the range of 600 to 1,200 psi are common, with continued strength increases up to 90 days.

Durability

The resistance to freezing and thawing of compositions containing CKD has been measured by the methods of ASTM C593. This method specifies that the compressive strength of vacuum saturated specimens should be used as a measure of freeze-thaw durability. A compressive strength of 400 psi is required on specimens that are vacuum saturated after being cured for 7 days. The results of a number of these tests are shown in Part II, Volume 2. The data represents compositions made from cement kiln dusts from five different sources. In each case, the minimum strength required for acceptance was obtained.

Autogenous Healing. There is significant evidence that compositions containing CKD possess the property of autogenous healing. Autogenous healing is the property that enables compositions that gain strength slowly over a long period of time to regain strength after their original strength has been exceeded and cracks have formed. It is typically evaluated by testing specimens in compression that have been previously tested to failure. The property of autogenous healing is of obvious benefit for a road base composition. It insures that continual rejuvenation of the structural capability of the base will take place over a long period of time. Damage to the pavement that is caused by temperature changes and load applications is neutralized by the continuous healing. Strengths of 100 percent to 160 percent of original have been measured after 2 to 4 months.

Laboratory Testing--Lime Kiln Dust

Compressive Strength. Compressive strength evaluations of potential base compositions utilizing lime kiln dust are performed in a manner identical to those where cement kiln dust is used. The laboratory data that were available for review on LKD was substantially less than for CKD. On the examples tested the seven-day strengths are on the order of 325 to 850 psi, slightly lower than a comparable lime-fly ash-aggregate composition.

Durability Tests. Limited data on freeze-thaw testing is available. However, the samples seem to be typical of hydrated lime-fly ash-aggregate compositions, in that there is a continued strength gain after twelve cycles of alternate freezing and thawing. The ability of the material to gain strength after a long period of adverse temperature variations indicates that any deterioration caused during cold weather will tend to correct itself when the temperature rises (probably at 55°F or higher).

Field Installations

Cement Kiln Dust. A number of field installations of road base consisting of CKD-fly ash-aggregate compositions have been made and are periodically evaluated. Table 6-2 shows the locations and extent of these installations together with other pertinent data.

Specimens have been removed from some installations and tested in compression. The most complete documentation of the performance of a field installation has been made on a road base in a concrete plant drive in Silica, Ohio. Test strips of six different mixes, each 100 feet long, were placed at this location. It is reported that "A total of 25,820 equivalent 8,165 kg (18,000 pounds) single axles were recorded in six months with no cracking or surface damage visible except for a localized area."

More recently, a recognized expert in the performance of stabilized road bases, inspected the Sherwin-Williams Company plant drives in June of 1980, approximately three years after they were constructed. He reported that the installations were in excellent condition. There was only a slight amount of cracking which is typical of stabilized bases of a similar type. The bituminous wearing surface was adhering properly to the base material.

Lime Kiln Dust. The Chicago area has been using a "polyhydrate" lime in lime-fly ash-aggregate compositions for several years. "Polyhydrate" lime can contain as much as 80 percent lime kiln dust and 20 percent quicklime. This experience has been successful and illustrates an application of LKD not previously identified.

The first field application of lime kiln dust using the formulations discussed in this report is scheduled for early November 1980 in the Toledo, Ohio area. Developers of the material feel that it will perform in a manner similar to the cement kiln dust compositions. This is based on the fact that the major constituent of portland cement is limestone and the sole raw material of lime is also limestone; therefore, the dust resulting in the processes should be similar. An examination of the chemical compositions of each indicates that there is a close similarity between cement kiln dust and high calcium lime kiln dust. No other field installations outside of the Chicago area of LKD were reported.

Table 6-2

FIELD INSTALLATIONS - CKD ROAD BASE COMPOSITIONS

Name and Location	Date Installed	Size	Thickness (Inches)
Silica, Ohio Plant Road	11/5/77	Six strips each 100 feet long	10
Meadowbrook Estates	October 1976	L 2,670' W 24' - 36'	5
Streets and Mobil Home Park	October 1976	L 220' W 24'	5
Toledo Express Airport Parking Lot	November 1978	5,000 square yards	8
Sherwin-Williams Company Plant Drives, Chicago, Illinois	10/19/77	L 500' W 30 '	6 to 10
John Ousky Park Parking Lot Oregon, Ohio	10/21/77	6,000 square yeads	5 to 6

Source: N-Viro Energy Systems, Inc., Toledo, Ohio.

Summary--Technical Assessment. The documentation that is available shows that kiln dust, fly ash, aggregate compositions have considerable potential in a road base application. The advantages are generally summed up in a recent report (Reference 6-6), and they are as follows. "Substitutions of CKD in place of lime to obtain a pozzolanic mixture provides at least three advantages.

a. Lower cost of material.
b. Enhancement of the environment by consumption of waste products which would otherwise require the use of land and other resources to store in a proper manner.

c. Lower energy consumption per mile of pavement, since both fly ash and CKD are by-products requiring virtually no energy for their production."

The laboratory data, which is mostly compressive strength testing of various compositions, shows a striking similarity to that obtained with proven hydrated lime, fly ash, aggregate road base compositions. This helps to substantiate the viability of using kiln dust in these applications.

There is also evidence to show that the variability of kiln dust, which is one of the chief disadvantages claimed by some, is not as great or as significant as has been stated. Sampling procedures for the kiln dust in the past appear to have largely ignored good sampling techniques and the process by which the material is produced and stored. Studies are now underway to verify the consistency of the significant properties of cement kiln dust when the material comes from a given location in the collection process. There appears to be no reason why the kiln dust should vary significantly if the raw materials and operating procedures of the plant remain constant. It is obvious that control of these two factors is also of vital importance to the quality of the primary product--cement or lime.

Five field installations of road base containing kiln dust prove that the material can be successfully used. It is obvious, however, that there are significant gaps in the information that is available. This is particularly true with regard to durability. There is also a need for larger, fully documented experimental field installations that will provide the type of information that will be convincing to potential users of road base materials. The Federal Highway Administration (supported by the U.S. Department of Energy) requested and received proposals for the evaluation of Kiln Dust-Fly Ash Systems for Pavement Bases and Sub-based (RFP #DTFH61-80-R-00056) in January 1980. This project is a laboratory evaluation, but a followup project involving experimental installations in three states is planned. Projects of this type will go a long way toward providing some of the additional documentation that is required.

Kiln dust is a promising material whose use should be developed by support of experimental work, including field demonstrations, that will prove its value. It is essential that the combined FHWA-DOE project, described briefly in the previous paragraph, be implemented without delay. There are strong reasons for utilizing kiln dusts, beyond their applicability in highway construction. Of great importance among these reasons is the energy saving involved in the use of a material that requires virtually no additional energy in its production and a reduced energy consumption during construction when compared to materials it would replace. There are also environmental and economic benefits derived from reduced disposal requirements.

SPECIFICATIONS

Because of the limited use of kiln dusts in stabilized base course applications, there are no standard specifications, nor any state specifications for routine use. However, it is anticipated that writing of such specifications will be a simple matter as kiln dusts will likely be allowed as an alternate to lime. Nevertheless, it is important to determine optimum amounts of kiln dust which will replace lime, and how to determine those optimum amounts in terms of specific applications and easily measurable properties of kiln dusts.

COSTS

Because of the limited application of kiln dust products, there is no price or cost history which can be evaluated. However, kiln dusts are viewed as replacements for lime, and at the present time the dusts are sold for substantially under the price of lime. Thus, under present conditions, it is probable that a product utilizing kiln dusts would be less expensive than competitive materials. However, the future price of dusts cannot be readily predicted, but it is unlikely that their price will ever exceed that of lime in equivalent use applications. Thus, we conclude that products using kiln dusts will be equivalent in cost or less expensive than conventional products.

ENERGY AND ENVIRONMENTAL IMPACTS

An assessment of the impact of kiln dust use on energy supplies and on the environment was made, and detailed results can be found in Appendix D. The assessment was made by comparing lime-fly ash-aggregate to an example product where the recovered material was submitted for a conventional product. The example chosen was a lime-fly ash-aggregate base, nine inches thick, 24-feet wide (2-lanes) and one mile long, compared to a similar base utilizing kiln dust as a replacement for lime. Figure 6-3 is a diagram of the operations considered, and Table 6-3 is a summary of the results.

Table 6-3

STABILIZED AND AGGREGATE BASE COURSE ALTERNATIVES
(One mile of 2-lane road)

	Lime-Fly Ash-Aggregate	Kiln Dust-Fly Ash-Aggregate
Energy (10^9 Btu)	3.9	2.7
Air Pollution (10^3 lb)	123	102
Water Pollution (10^3 lb)	1.5	1.2
Processing Solid Waste (10^3 lb)	90.6	9.9
Materials Diverted from Waste (10^3 lb)	1,500	2,600

Source: Franklin Associates, Ltd.

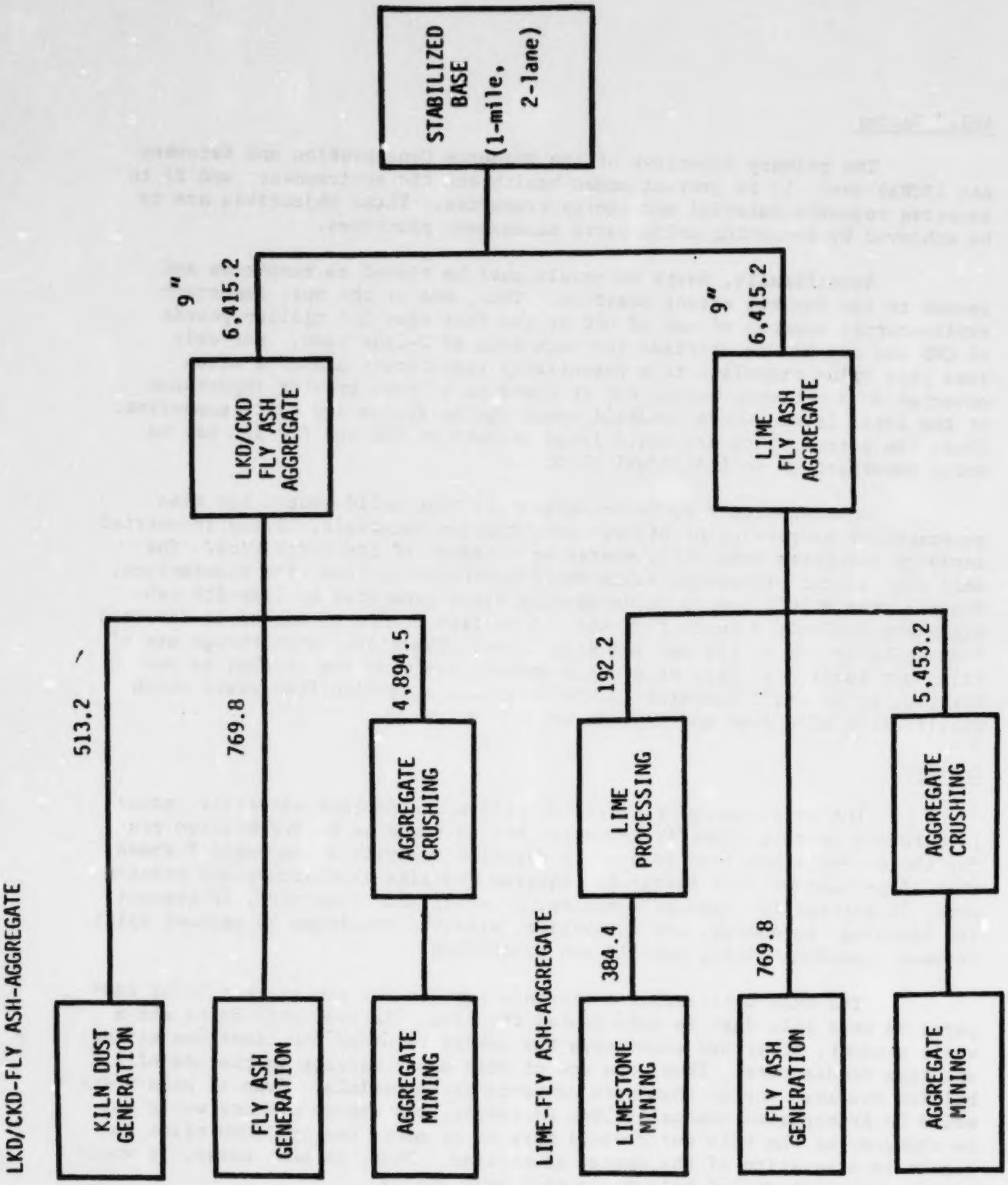
LKD/CKD-FLY ASH-AGGREGATE
KILN DUST GENERATION
FLY ASH GENERATION
AGGREGATE MINING
AGGREGATE CRUSHING
513.2
769.8
4,894.5
LKD/CKD FLY ASH AGGREGATE
6,415.2
9"
STABILIZED BASE (1-mile, 2-lane)
LIME-FLY ASH-AGGREGATE
LIMESTONE MINING
384.4
LIME PROCESSING
192.2
FLY ASH GENERATION
769.8
AGGREGATE MINING
AGGREGATE CRUSHING
5,453.2
LIME FLY ASH AGGREGATE
6,415.2
9"

Figure 6-3. Materials flow for stabilized base (tons).

Solid Wastes

The primary objective of the Resource Conservation and Recovery Act (RCRA) are: 1) to protect human health and the environment; and 2) to conserve valuable material and energy resources. These objectives are to be achieved by improving solid waste management practices.

Specifically, waste materials must be viewed as resources and reused to the maximum extent possible. Thus, one of the most important environmental aspects of use of CKD is the fact that 2.6 million pounds of CKD and fly ash is utilized for each mile of 2-lane road. Not only does this value translate to a potentially significant use of a waste material on a national basis, but it could be of even greater importance at the local level, where landfill space may be scarce and quite expensive. Thus, the potential to use quite large amounts of CKD and fly ash may be quite important to an individual plant.

Another factor to be considered is that solid wastes are also generated by processing of highway construction materials. Every industrial activity generates some solid wastes as a result of its activities. The only significant processing solid waste generated is from lime manufacture. However, the 91,000 pounds of processing waste generated by lime-fly ash-aggregate use only 3 percent of the 2.6 million pounds of materials diverted from waste by use of fly ash and kiln dusts. Therefore, even though use of kiln dust results in less processing wastes, and even though that is desirable, it is small compared to the materials diversion from waste which results from kiln dust and fly ash use.

Energy

The total energy required to obtain and process materials, manufacture and install lime-fly ash-aggregate is found to be 3.9 billion Btu for the one-mile two-lane road. The detailed analysis of Appendix D shows that 32 percent of that energy is required for lime manufacture and transport, 30 percent for aggregate mining, crushing and transport, 28 percent for batching, spreading, and compacting, with the remaining 10 percent split between limestone mining and fly ash processing.

The only substantial difference between the two systems being compared is that kiln dust is substituted for lime. Because kiln dusts are a waste product, their use eliminates the energy required for limestone mining and lime manufacture. Thus, the use of kiln dusts results in the use of 1.2 billion Btu less energy than with conventional materials. Even if kiln dusts would be transported unusually long distances, the energy picture would not be changed, as the kiln dusts would have to be moved nearly 5,000 miles to result in a negation of the energy advantages. Thus, in most cases, it would be expected that use of kiln dusts will save energy.

Air Pollution

The predominant air pollution problem for either product is particulates, primarily resulting from dust generated during aggregate mining and crushing, and to a lesser extent from handling fly ash and kiln dusts. Lime manufacture results in about 7 percent of the air pollution generated. Table 6-3 shows that less air pollution is generated by the kiln dust systems, primarily because slightly less aggregate is used, and because manufacture of lime is avoided. However, copius quantities of dust can be produced in the handling of either fly ash or kiln dusts. If these materials are handled properly (in closed equipment for loading, unloading, storage, and transports) and are applied using proper wetting, then the results in Table 6-3 are valid.

Water Pollution

There is no significant direct water pollution associated with the products discussed here. The only water pollution associated with these systems results from production and refining of fuels. Thus, because use of kiln dusts results in energy savings, it also results in less water pollution. However, the amounts involved are quite small relative to other factors considered.

Another potentially important source of water pollution related to materials in construction applications is leachate. Leachate production from "in place" products and composition are related to solubility, permeability, and chemical composition.

Generally, water penetration through the products studied is relatively low, as the permeability is quite low. This minimizes any potential leachate problems. The toxic substances contained in the materials can be determined by chemical analysis of the material itself, and are found to be primarily heavy metals. With respect to these toxic substances, the Environmental Protection Agency has established a guideline for Safe Drinking Water Standards. A concern exists if the extract from the material (obtained by a testing means such as the EP toxicity test method) has a concentration of any constituent greater than one hundred times the established water standard.

As a part of this research project, one sample was obtained from an existing base in which cement kiln dust had been utilized. This sample was subjected to leachate extraction procedures, with the leachate being subsequently evaluated by standard laboratory procedures. The procedures used were in accordance with EPA recommendations.

Included in Appendix E, Volume 2, is a description of the method used in the leaching tests, the Federal Register notice describing the "EP Toxicity Test," and a summary of the results.

Although the single test performed was not of sufficient magnitude to extrapolate the results to all highway construction products containing recovered materials, the test does not indicate that there is an environmental hazard. As far as is known, there are no known leachate extraction test results from field highway construction samples that do indicate any significant toxic leachate associated with this kind of use.

Summary

It is clear that the energy and environmental impact of using kiln dusts is quite positive. Use of fly ash and kiln dusts in pozzolanic bases can result in 2.6 million pounds of waste use for each mile of 2-lane road. In addition, 1.2 billion Btu of energy may be saved. Also, air and water pollution may be reduced a small amount as a side benefit. Thus, use of these waste materials clearly result in substantial benefits.

GUIDELINE OPTIONS

At the present time, there has been very little experience in the use of kiln dusts in highway construction. In fact, the use of such materials are characterized only by initial field tests. There are not adequate supplies of quality controlled dust in many locations, and little experience in manufacture of dust products. In fact, no state or Federal standard specifications exist. Thus, any Federal requirements to encourage the use of kiln dusts in routine applications would seem to be premature. The only viable guideline options would seem to be only those that include encouragement to advance research and field testing, or to state intent to require or encourage use at some point in the future.

One problem which a guideline either now or at some future date will have to deal with is the fact that kiln dusts will likely never be available in all regions of the country. Thus, any guidelines for use will have to be written so as to properly account for this. One possibility would be to simply write a use guideline to cover all states, and let those states that never can use kiln dusts simply process the paperwork and other inconvenience which might be required for dual bids or other use guidelines. Alternatively, the guidelines could be made applicable only to certain regions where kiln dusts are the most serious waste disposal problem. For example, in five EPA regions, generation of dusts now exceeds 2 million tons per year.* Guidelines could be made applicable to those regions only, or guidelines could be made to apply to selected states with severe waste problems, with some selection procedure being developed for a lower cutoff point. Thus, New Mexico, which is in Region 6, but has relatively low waste generation would be excluded.

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* They are Region 4 (Kentucky, Tennessee, North Carolina, South Carolina, Mississippi, Alabama, Georgia, Florida); Region 5 (Minnesota, Wisconsin, Michigan, Illinois, Indiana, Ohio); Region 6 (Texas, New Mexico, Oklahoma, Arkansas, Louisiana); Region 7 (Kansas, Missouri, Iowa, Nebraska); Region 9 (California, Nevada, Arizona, Hawaii).

Another alternative would be to combine this guideline with the guideline for lime-fly ash-aggregate bases. Kiln dusts could be allowed as a substitute for lime. Thus, a separate guideline would not be needed. However this would not be feasible until sufficient testing has been done to establish the exact conditions under which such a substitution would be technically appropriate.

Increase Funding for Research and Testing

Because the optimum applications for kiln dusts are to some extent still in doubt, and because basic chemical and physical reactions are not well understood, FHWA could make kiln dusts a priority research item. As reported earlier, FHWA already has underway a program for research, testing, demonstration, and evaluation, but this effort could be expanded, and a more comprehensive and more widespread testing program would be possible if funds permitted. However, FHWA plans to embark on a demonstration program for uses of fly ash in highway construction, including kiln dust-fly ash-aggregate base course compositions.

Advantages. An advantage of this option is that it would decrease the time until kiln dust use is better understood. This would improve the user's ability to wisely incorporate kiln dusts in road construction and also increase the reliability of the installation.

Disadvantages. The main disadvantage would be that FHWA would likely have to divert research funds from other projects which they have identified as being more important. Thus, a basic policy decision would need to be made that it is more important for FHWA to conduct research alleviating a solid waste problem than to fund research solely on a product's merit as a highway construction material. FHWA has already allocated money to kiln dust research and evaluation. Therefore FHWA has made judgments as a part of their overall priorities. This option would essentially require them to alter those decisions in favor of funding more research on kiln dusts.

An alternative may be additional funding by Congress for these activities. If use of recovered materials is deemed to be in the national interest, this would be justification for increasing the FHWA budget in order to fund these activities.

An additional alternative is for joint funding of these activities with another agency. Both FHWA and DOE are co-funding a current research and evaluation project on LKD-FA-aggregate base courses, so increased funding might potentially be shared on this basis.

Delay Guideline Implementation

Another guideline option is to delay implementation of a specific guideline option for a specified number of years. For example, EPA could publish their intent to implement a dual bid or other use guideline in 5 years. Alternatively, EPA may simply state an intent to review the situation in 5 years and reach a guideline decision at that time. However, it is probable even then that a guideline would not be applicable to all regions of the country.

Advantages. An advantage of this option is that it would delay definite action in view of the fact that there are still many unknowns concerning the use of kiln dusts. In 5 years, many test strips could be placed and evaluated, and the picture on how and where kiln dusts can wisely be used will be clearer. In addition, a formal notice by EPA of the intent to implement a guideline for kiln dusts would give procuring agencies time to develop specifications and to plan on the best use of the material and how best to comply with a guideline.

Disadvantages. The primary disadvantage of this option is that it would delay any definitive action by EPA and would postpone any possible benefits of a guideline.

Chapter 6

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Chapter 7

USE OF RUBBER TIRES IN HIGHWAY CONSTRUCTION PRODUCTS

INTRODUCTION

One of the most persistent and stubborn problems facing landfill managers is rubber tires. It is estimated that in 1977 approximately 220 million auto tires and 20 million truck tires were discarded by consumers (Reference 7-1).* In addition, an estimated 1-1/2 to 2 billion tires are recoverable from stockpiles.**

The problem with tires in landfills is that they do not compact well; they hold water which creates disease vectors and odor problems; and they tend to work to the surface of the landfill, or "float." This can be alleviated by splitting or shredding, but this is a relatively expensive operation. Tires can also be incinerated, but this has also proved to be an expensive solution.

An attractive possibility is to reuse the tires in some way, thus avoiding the disposal problem. At the present time, one tire in five is reused by retreading, and another one in 20 is routed to a rubber grinder or reclaimer, which processes the rubber for use in products such as tires, asphalt rubber and in many other rubber products (Reference 7-1). A currently small, but potentially important, application of rubber tires is addressed here--the use of discarded tires in an asphalt-rubber mixture.

WASTE RUBBER TIRE GENERATION AND RECOVERY

Waste rubber tires are generated by users of cars and trucks, either when replacement tires are purchased for the vehicle, or when the vehicle itself is sold to the scrap market. The consumer customarily trades the old tires for new ones at the point of purchase, and the tire dealer (or vehicle dismantler) must then find an outlet for the used tires. These tires go on one of four paths to reuse or discard as shown in Figure 7-1. The four paths lead to retreaders, reclaimers and grinders, splitters or final disposal. In the case of truck tires, virtually all are sold to retreaders, and those which can't be used by retreaders are sold primarily to splitters or go to disposal.

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* See references at the end of the chapter.

** The flow of tires through the economy is not well documented, and different authors do not agree on the number of rubber tires discarded or diverted from waste. However, the differences are insignificant for this study.

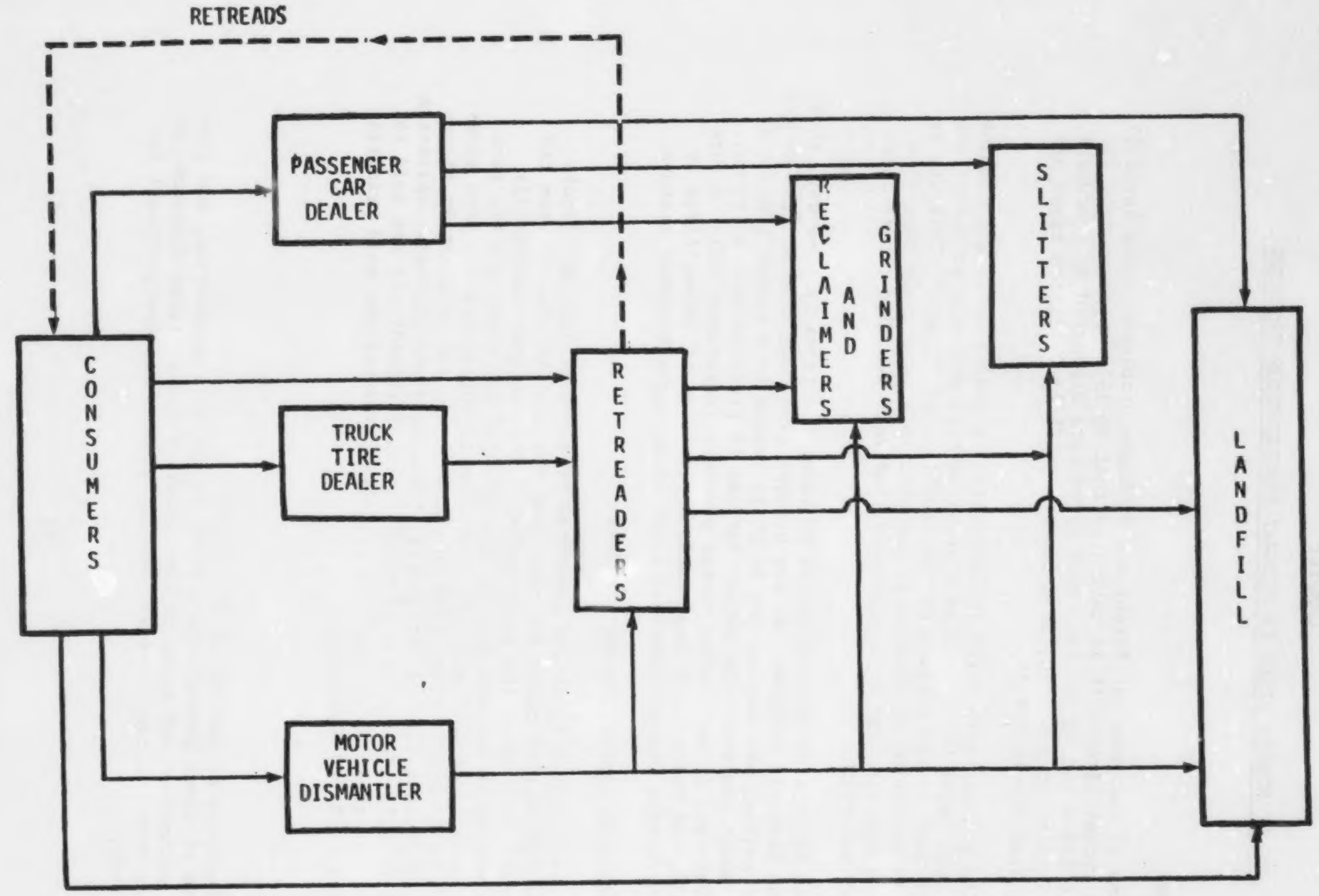
RETREADS
CONSUMERS
PASSENGER CAR DEALER
TRUCK TIRE DEALER
MOTOR VEHICLE DISMANTLER
RETREADERS
RECLAIMERS AND GRINDERS
SLITTERS
LANDFILL

Figure 7-1. Rubber tire use, reuse, and discard patterns.

Most used tires that are not discarded go to retreaders. It has been established that in 1978, 37 million car tires and 11 million truck tires amounting to 980,000 tons of tires were retreaded and sold (Reference 7-5). The second largest market for tires was reclaimers and grinders with a consumption of 130 thousand tons in 1978. Tire slitters consumed 10 thousand tons in 1978. In the slitting process, the tire is slit into a tread section and two sidewall sections. These sections are cut to a uniform thickness, and then die cut or punched to form salable products such as muffler hangers and boat dock bumpers.

The focus of interest in this study is on the reclaiming and grinding segment, which produces forms of used rubber which can be blended with asphalt to produce asphalt-rubber. In the case of rubber reclaiming, the tires are shredded, and metal and fabrics are removed. The rubber is then subjected to heat and chemical processing which "devulcanizes"* the rubber. Reclaimed rubber disperses well in asphalt, but it is usually mixed with ground rubber in order to achieve desired properties of resilience and toughness.

In a grinding operation, a crumb rubber is produced, which can be utilized to make asphalt-rubber. Ground rubber is produced by a purely mechanical process, so that the chemical properties of the tire rubber are preserved. The tires are first shredded, and then metal and fabrics are removed. The shredded rubber is put through a final grinding operation, sized, and packaged. In some cases, before the final grinding, the rubber is subjected to liquid nitrogen. This freezes the rubber and makes it quite brittle, which facilitates grinding. Truck tires are an important raw material for crumb rubber used in asphalt-rubber manufacture because they contain natural rubber, which is needed to achieve optimum final product properties.

QUANTITIES OF WASTE RUBBER

National Generation

As shown in Table 7-1, the national generation of waste tires was 3.8 million tons in 1978. Twenty-eight percent of this generation, or 1.1 million tons, was recovered and used to manufacture new products. Still, 2.7 million tons were sent to final disposal.

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* Devulcanization is a process which results in a partial reversal of vulcanization, or a partial chemical breakdown of the rubber.

Table 7-1

WASTE RUBBER TIRE GENERATION, RECOVERY, AND FINAL DISCARD - 1978
(Thousand tons)

Gross Waste Tire Generation 1/	3,810
Tire Recovery for Reuse and Recycling	
Retreaders	930
Reclaimers or Grinders	130
Slitters	10
Other	10
Subtotal	1,080
Discard to Final Disposal	2,730

1/ This includes car and truck tires (and tubes) which have ceased to be of utility to the consumer and are discarded to waste or to some reuse or recycling system.

Source: Reference (7-5).

Geographical Generation Pattern

State by state data on waste tire generation does not exist, but a methodology was developed to estimate the geographical distribution. The 3.8 million tons were apportioned to the states based on vehicle registrations. The results are summarized in Table 7-2 and Figure 7-2. As can be seen, the tire generation is heaviest in seven states--California, Texas, Ohio, Pennsylvania, Michigan, Illinois, and New York, all of which generate over 150,000 tons per year. Twenty-eight states generate less than 50,000 tons of waste tires per year each, as compared to California where an estimated 300,000 tons per year are generated.

Waste tires have a relatively low value although their value fluctuates greatly as is true for most scrap materials. However, waste tires are generally not transported more than 200 to 300 miles because the transportation costs will exceed their value. Because tires are quite bulky, their transport is more expensive than for many materials. Thus, most rubber grinding and reclaiming plants are located close to significant sources of supply. However, after the rubber is processed it has a much higher value, making long distance transport more feasible. Also, the freight rates are more reasonable, as processed rubber is in a much more dense form. Reclaimed and crumb (ground) rubber is in fact shipped to virtually all parts of the country so that geographical concentration of plants is not always a deterrent to obtaining adequate supplies for uses such as highway construction.

Table 7-2

TOTAL ANNUAL GENERATION OF WASTE TIRES IN 1978 BY STATE AND EPA REGION

(Thousands of tons)

EPA Region 1	
Massachusetts	78
New Hampshire	13
Connecticut	48
Maine	19
Rhode Island	15
Vermont	8
Total	181
EPA Region 2	
New York	235
New Jersey	115
Total	350
EPA Region 3	
Pennsylvania	209
Maryland	61
West Virginia	30
Virginia	74
District of Columbia	18
Delaware	10
Total	402
EPA Region 4	
Kentucky	57
Tennessee	78
North Carolina	85
South Carolina	35
Mississippi	44
Alabama	62
Georgia	80
Florida	123
Total	564
EPA Region 5	
Minnesota	85
Wisconsin	71
Michigan	152
Illinois	183
Indiana	104
Ohio	208
Total	803
EPA Region 6	
Texas	241
New Mexico	24
Oklahoma	63
Arkansas	46
Louisiana	73
Total	447
EPA Region 7	
Kansas	57
Missouri	123
Iowa	84
Nebraska	47
Total	311
EPA Region 8	
Montana	24
North Dakota	19
South Dakota	20
Wyoming	10
Utah	26
Colorado	63
Total	162
EPA Region 9	
California	380
Nevada	12
Arizona	46
Hawaii	8
Total	446
EPA Region 10	
Washington	67
Oregon	54
Idaho	19
Alaska	4
Total	144
Total U.S.	3,810

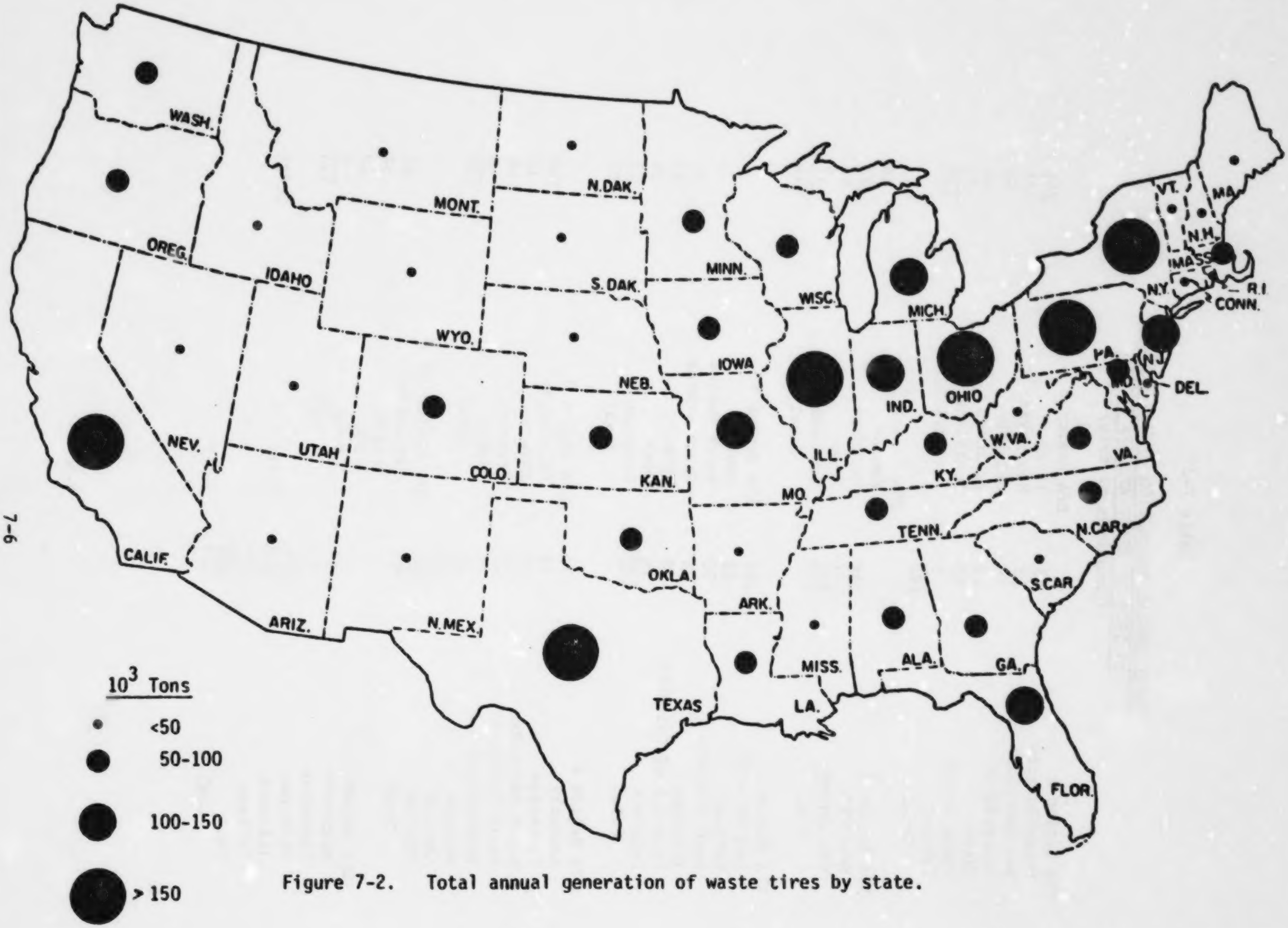
WASH.
OREG.
CALIF.
NEV.
IDAHO
MONT.
WYO.
UTAH
ARIZ.
COLO.
N.MEX.
N.DAK.
S.DAK.
NEB.
KAN.
OKLA.
TEXAS
MINN.
IOWA
MO.
ARK.
LA.
WISC.
ILL.
MISS.
MICH.
IND.
KY.
TENN.
ALA.
OHIO
W.VA.
VA.
N.CAR.
S.CAR.
GA.
FLOR.
PA.
N.Y.
VT.
N.H.
MA.
MASS.
R.I.
CONN.
N.J.
MD.
DEL.
10^3 Tons
● <50
● 50-100
● 100-150
● > 150

Figure 7-2. Total annual generation of waste tires by state.

Current Use Patterns

A common fate of a discarded tire is to go to final disposal. However, 63 percent of the tires are first sent to a retreader who examines the tires for retreading suitability. He retreads about 20 percent of the tires discarded (about one-third of the tires received), sending the remainder on to final disposal (Reference 7-1). Perhaps as many as 14 million tires per year--5 to 6 percent of total discard--go to reclaimers and grinders. The product of these plants is used by the asphalt-rubber industry, although this use is at present a minor fraction of the output of the reclaimed and crumb rubber industry. According to Hittman (Reference 7-1), 64,000 tons of reclaim rubber was consumed in 1977, most of which was consumed by the tire industry. The same source estimates that nearly 18,000 tons of crumb rubber was produced by grinding. The tire industry is a major user along with manufacturers of many special rubber products which blend crumb rubber with other rubber materials.

Based on Miller's estimates (see Part III, Volume 2), it appears that in 1980, not more than 5,000 tons of reclaimed and crumb rubber were used in asphalt-rubber. Although current reclaimed rubber statistics are not accurate, it is doubtful that asphalt-rubber accounts for more than 5 percent of consumption of reclaimed and crumb rubber produced.

It is concluded that reclaimed and crumb rubber is now available in all parts of the country, although there may be significant transportation required in some cases. It also appears that consumption of reclaimed and crumb rubber by the present asphalt-rubber industry is a small but significant fraction of the total produced. Any significant expansion of use of asphalt-rubber would have to take into account possible requirements for new crumb rubber supply.

ASPHALT-RUBBER

Description

A blend of rubber and asphalt is known simply as asphalt-rubber. Rubber is mixed with asphalt after the asphalt has been heated to a temperature of 350° to 425°F. Heating of the mixture is continued for a period of between 30 and 90 minutes. It is applied to roadways while hot. In those highway applications where the material is applied in a layer which will be subjected to traffic, a layer of stone (chips) is immediately spread and rolled into the still hot asphalt-rubber.

The recovered material in asphalt-rubber is rubber tires. It is a granulated product produced by grinding and processing scrap automobile and truck tires. The rubber usually is reduced to a size such that 100 percent is finer than a No. 10 sieve (2.00 mm opening).

The introduction of rubber into the asphalt is intended to improve the resulting binder in three ways:

1. Improves its response to temperature change by reducing the low temperature at which it becomes "glassy" (brittle), and increasing the temperature at which it softens;
2. Improves its long-term durability;
3. Improves its ability to adhere to aggregate.

There are seven present and potential applications for asphalt-rubber: 1) SAMI (stress absorbing membrane interlayer); 2) chip seals;* 3) waterproofing membrane; 4) crack and joint sealant; 5) bridge deck waterproofing; 6) hot mix binder; and 7) roofing material.

The present study is concerned primarily with uses (1) and (2) above. Uses (3) and (4) appear to have progressed beyond the experimental stage, but these current and near term projected markets are quite small when compared to uses (1) and (2), and will not be considered here. Uses (5), (6), and (7) are still very much in the experimental stage and will also not be considered.

A comparison of two asphalt-rubber products is shown in Table 7-3. Projects supplied by one of the companies date back to 1962, while the other supplier has more recently entered the field (1975). The results obtained by either supplier appear to be comparable. It is difficult, however, to fully document this conclusion because of the disparity in the length of history of each.

Commercial Availability

The longest history of use and the greatest volume of use of the asphalt-rubber product have been in Arizona. Asphalt-rubber is readily available in that state from two suppliers. The recycled rubber that goes into the asphalt-rubber is obtained from out-of-state sources in California and Mississippi. This, too, is readily available and of satisfactory quality. A new modern facility for processing recycled rubber is under construction in Phoenix and was scheduled to go into production in early 1980 (see Part III, Volume 2). As for further availability, facilities will be forthcoming as the market develops. There is an ample supply of scrap tires. Plants for recycling the rubber are scattered throughout the country, and a new plant

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* When chip seals are used over a distressed (severely cracked) pavement, it is sometimes referred to as SAM (stress absorbing membrane). If it is covered with an overlay, it becomes a SAMI.

Table 7-3

COMPARISON OF ASPHALT-RUBBER PRODUCTS

Supplier	Asphalt-Rubber Composition: Rubber	Asphalt-Rubber Composition: Asphalt	Asphalt-Rubber Composition: Other	Distributor Truck	Asphalt-Rubber Mixing Process	Remarks
Sahuaro Petroleum and Asphalt Co.	Ambient ground 25 + 2% by weight of asphalt-rubber mix.	Various penetration and viscosity grades - 120-150, 200-300, AR-1000, and AR-2000, AC-5, and AC-10 are typical	Up to 7-1/2% diluent may be added, normally 3 to 5% used	Special internal mixer, heater and onboard electronic scales	Combined in blender unit. Transferred to distributor for mixing & reaction. Process is closely monitored.	Mixing Temp. 350°-395°F. Application temperature 290-325°F
Arizona Refining Company 1/	40% powdered devulcanized rubber, 60% powdered vulcanized rubber with 0.30% minimum natural rubber content. 20% + 2% by weight of asphalt-rubber mix	AR-4000 or 8000	2%-6% aromatic extender oil (lube extract) is added if asphalt is deficient in aromatic oil	Conventional	Batch process in any tank that provides for mixing by recirculation, stirring, air agitation or other appropriate means & heat exchanger & temperature controls. 2/	Mixing temp. 350°-400°F Application temperature 375°-425°F

1/ ARCO ARM-R-Shield process is detailed in U.S. Patent 4,068,023.
2/ It is claimed that mixing can be done in conventional pressure distributor truck.

Source: Valley Forge Laboratories, Inc.

can be put into service within 12 to 15 months of a decision to proceed. Special distributor trucks have been manufactured by one company in Arizona. They are now capable of building trucks at the rate of approximately 15 to 20 per year, so that they could accommodate fairly rapid expansion of demand. In addition, one of the processes uses conventional distributor trucks that are available from several sources. The lack of availability of personnel experienced in the use of asphalt-rubber could be a temporary bottleneck to development. With the probability that use of the product will develop slowly over a long period of time, there does not appear to be any constraint due to availability of the recovered material.

In assessing the ability of asphalt-rubber suppliers to meet the demand, the following aspects have been studied: availability of the asphalt-rubber mixture (including availability of equipment), and the availability of experienced personnel to insure proper construction.

Availability of the Asphalt-Rubber Mixture (Including Availability of Equipment)

There are two major suppliers of the asphalt-rubber mixture in the U.S. Both are located in Phoenix, Arizona. These companies operate not only in Arizona but throughout the United States. One company is capable of supplying, with their present capacity, 100 tons of asphalt-rubber per day. Approximately 15.8 tons of asphalt-rubber is used per lane-mile. At these rates, it would be possible to supply 6.3 lane-miles per day. Since their system involves the use of conventional distributor trucks, they could provide additional capacity quickly. The heating of the asphalt and the mixing of the rubber with the hot asphalt takes place in the distributor truck. After allowing the proper time for the asphalt-rubber reaction to take place, the material is sprayed on the roadway.

It was not possible to obtain accurate information on the capacity of the other supplier. This company uses special distributor trucks. In early 1978, it was reported that they owned 16 of these trucks. They are, however, constantly developing, in cooperation with a truck manufacturer, new equipment to improve productivity and quality of their product. A separate heater-blender has been produced that apparently can be used with conventional distributor trucks. This equipment increases mobility and reportedly removes a restrictive factor to productivity on the job site. This producer sends trucks all over the United States and into Canada. A route established in the early part of the construction season enables them to start work in the warmer locations and proceed to the colder areas. The company maintains that they have no problem in handling present demand and are capable of handling approximately twice the current production.

Thus we conclude that asphalt-rubber is available in all locations in the U.S., but only in limited supply. However, the supply could readily expand to meet demand if an orderly market prevails--that is, if growth is not precipitous.

Although there is no official record of the magnitude of asphalt-rubber production, an estimated generation figures is given in Table 7-4.

Table 7-4

REPORTED PRODUCTION OF THE LARGEST SINGLE SUPPLIER OF ASPHALT-RUBBER

Year	Tons of Asphalt-Rubber	Year	Tons of Asphalt-Rubber
1970	500	1976	12,800
1971	1,200	1977	13,800
1972	1,600	1978	16,660
1973	3,400	1979	26,400
1974	3,400	1980	33,000
1975	6,200		

Source: Reference 7-2.

It is estimated that four tons of rubber would be needed per lane-mile for a typical asphalt-rubber application. It would be theoretically possible, therefore, on the basis of the 2.5 million tons of rubber tires available annually to use asphalt-rubber on over 600,000 lane-miles per year. The 50,000 tons of rubber estimated as a potential demand* represents less than 2 percent of the amount available. Estimated total usage to date of 8,250 tons of rubber represents 0.3 percent. The estimates used are admittedly rough and this should be kept in mind in drawing conclusions from them. It is obvious, however, that the availability of the raw material (scrap tires) is ample for even the most optimistic estimates of demand.

Availability of Experienced Personnel

Assuming that adequate specifications relating to design, materials, quality control, and construction have been developed, there are two operations that require the availability of experienced personnel. They are: (1) acceptance testing of materials and the design of satisfactory mixtures in cases where materials are to be combined, and (2) the actual construction work in which the material(s) is utilized. The most often used statement by people who work with asphalt-rubber is "good results are obtained if it is used properly by people who know what they're doing." In each jurisdiction in which the material is to be used at least one person should have intimate knowledge of the laboratory procedures and one should have detailed knowledge of the construction practices. The jurisdictions would include the city, county, and state agencies that are normally responsible for conducting these activities. These individuals would then be available to train additional personnel in the techniques that are peculiar to the materials.

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* See page 7-13 for a description of the potential demand.

In addition to the requirements for trained personnel on the part of the users, it will be necessary to have their counterparts in the employ of the producers.

The Federal Highway Administration, through its Demonstration Projects Program, FHWA-DP-37, has initiated a technology transfer activity that will support the training of new personnel. As of September 1979, asphalt-rubber projects were constructed or planned in 23 states. It is estimated that a total of 70 individuals, either experienced laboratory or construction people, were introduced to the techniques of using asphalt-rubber.

Current Use Patterns

It is impossible to determine an exact quantity for the demand for asphalt-rubber products. It is, however, possible to develop gross estimates that are based primarily on the history of past and current usage.

Approximately 200 lane-miles have been placed in the City of Phoenix with an additional equivalent of 51 lane-miles on the south runway of Sky Harbor Airport (Phoenix).* Reference 7-7 is a report based on "Results from approximately 2,000 lane-miles of construction..." The report was prepared in 1975. Since that time asphalt-rubber was placed on an estimated 200 kilometers of 2-lane low traffic roads (250 lane-miles) in the Canadian province of Saskatchewan as of spring, 1980. The anticipated production for 1980 was 186 kilometers or 230 lane-miles. The results have been so encouraging that the use of asphalt-rubber on low cost roads in Saskatchewan is almost routine. There are approximately 6,000 miles of these roads, with an average daily traffic no greater than 800 vehicles per day, in the Province. In an article on "Rubber Asphalt" in the April 1979 issue of Construction West Magazine, an official of the Saskatchewan Highway and Transportation Department is quoted as follows: "Just from rough calculations we are looking at using all the rubber we can get our hands on in Saskatchewan. Even on the pessimistic side we're looking at requiring 7,000 tons a year." In the same publication he is also reported to have said that the future of rubberized asphalt in Saskatchewan will depend on the supply of rubber and its cost. Additional mileage of experimental sections has been placed throughout the United States in connection with the FHWA Demonstration Projects. It is believed that the total usage has been less than 10,000 lane-miles. Sahuaro Petroleum and Asphalt Co. says in promotional literature "Proven on over 8,000 lane-miles." Even with these rough figures, it can be seen that the potential supply of recycled rubber would far exceed the demand for its use in highways.

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* Computed from data given in Reference 7-4.

Potential Use

A crude forecast of potential usage of asphalt-rubber could be based on the experience, to date, in Arizona. Current practices indicate that an application rate of 4-1/2 pounds or 0.6 gallons of asphalt rubber per square yard of road surface is required. Twenty-five percent of this is rubber or 1.1 pounds per square yard of road surface. Assuming a 12-foot wide lane, there are 7,040 square yards per mile for one lane. This amounts to approximately 8,000 pounds (4 tons) of rubber per lane-mile. If the 2,000 lane-miles constructed in Arizona were assumed to occur between the first full-scale trial (1967) and 1975, a period of 8 years, the production rate would be 250 lane-miles per year. This would use 1,000 tons of rubber annually. Assuming that this would be the average consumption in each state, a total of 50,000 tons would be involved. More accurate estimates are not possible because of the lack of available information on the miles of road which would be most suitable for asphalt-rubber application.

The amount of potential demand for the two major uses of asphalt-rubber, as a chip seal and as a stress absorbing membrane interlayer, is related to the amount of serious deterioration in the condition of existing pavements. This is because the evidence suggests that both of the above applications should be used only on pavements that show excessive cracking. It is apparent that many existing roadways are approaching this condition, so it can at least be assumed that there will be substantial demand for a product such as asphalt-rubber that is effective in controlling these cracks.

TECHNICAL PERFORMANCE

Introduction

The consensus is that asphalt-rubber is a unique product having distinct properties than enhance its use as a paving material in rather well-defined situations. It has been particularly effective as a technique for restoring and increasing the life of distressed (cracked) bituminous pavements. Highway pavements, portland cement concrete as well as bituminous, are subjected to destructive forces such as traffic and climate immediately after they are put into service. Eventually, these forces cause deterioration of the pavement to the extent that corrective measures are required. In many cases, the pavement is severely cracked and may be marked with a substantial number of pot holes. In the past, bituminous overlays of one inch or more in thickness have been used over the cracked pavement in order to restore its serviceability. One of the disadvantages of this type of remedy has been that in a relatively short period of time cracking of the overlay occurs at the same places that the original distressed pavement was cracked. These cracks in the overlay are commonly referred to as reflected cracks. Reflection cracking can be appreciably delayed and/or reduced by the proper use of asphalt-rubber.

An understanding of the various types of cracks that occur in highway pavements is necessary in order to understand why asphalt-rubber is effective in their control. There are three types of cracks:

Load Associated

- fatigue cracking--due to repeated deflection of the pavement caused by traffic loads
- cracks caused by differential vertical movement

Nonload Associated

- cracks caused by direct tensile stress--usually caused by temperature change or shrinkage of the paving material

The formation of these cracks is resisted by a material that has sufficient elasticity to enable it to deform under stress without rupturing.

The use of rubber in asphalt has a direct effect on two important properties: 1) it improves the elasticity of the asphalt; 2) it reduces the susceptibility of the asphalt to changes in temperature. It, therefore, makes the asphalt-rubber more elastic and keeps it in this condition at temperatures 20 to 30°F lower than conventional asphalt.

When the layer of asphalt-rubber and chips is placed as a surface layer (SAM) on top of a cracked pavement, it has been shown to be effective in controlling fatigue cracks. The underlying cracks do not come through the SAM for a much longer period of time than if a conventional seal coat is used. As an interlayer (SAMI), where a 2 to 4 inch bituminous overlay is added on top, it appears to control all types of cracking. In both these instances, little or no maintenance is required for extended periods.

Laboratory and Field Tests

One of the most comprehensive analyses made on the effectiveness of asphalt-rubber for crack control is presented in Reference 7-6. Eighteen selected roadway test sections were evaluated in this study, which was carried out on a nine-mile section of Interstate 40 near Winslow, Arizona. Among five treatments "found to have significantly reduced reflection cracking" were listed: "Aspahlt-rubber membrane seal coat under ACFC* and asphalt-rubber membrane flushed into asphaltic concrete overlay." The report also recommended that one of the five treatments "be used in conjunction with a thin overlay (less than 4 inches of AC)." In 1978, 6-1/2 years after construction, the asphalt-rubber membrane seal coat under ACFC showed the least amount of reflective cracking of the 18 test sections. By that time, the highway had been subjected to substantial repeated leveling. The following statement is also included in the above report: "As a result of this project and other evidence, ADOT implemented in 1975 the use of the stress absorbing interlayer (SAMI) as standard procedure for all overlays under four inches in thickness that are placed over pavements where cracking is a problem."

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* ACFC stands for Asphaltic Concrete Friction Course.

A recent analytical study has also determined that "the effect of including a low modulus interlayer (rubber asphalt) can be significant in the inhibition of reflection cracking resulting from both load and temperature changes,..."

The Corps of Engineers is also evaluating asphalt-rubber installations at several locations. The data shown in Part III, Volume 2 presents preliminary information on the extent of reflection cracks in test sections designed to evaluate the crack control provided by various systems. The asphalt-rubber sections are located at Ft. Stewart, Georgia and Ft. Devens, Massachusetts.

The test results of these sections are inconclusive and it is felt that there has been an insufficient lapse of time for reflective cracking to occur.

Additional roadway test sections have been constructed at three other Army locations: Ft. Lewis, Washington; Ft. Carson, Colorado; and Ft. Polk, Louisiana. In these tests, a SAMI has been placed under a thin (1-1/2 inch) overlay. At Ft. Polk, Louisiana the existing pavement is a 6-inch portland cement concrete slab with a 2-inch bituminous concrete overlay. At the other two locations, the existing base is crushed stone or gravel with a 1-1/2 inch bituminous surface. Evaluation of these sections is continuing; the results, as yet, are not conclusive, and a final report will be issued when sufficient time has elapsed.

The Corps of Engineers seems to have the present position that the use of asphalt-rubber is still in the experimental stage and its long-term benefit has not as yet been proven. They have obtained funding at the Waterways Experiment Station for a laboratory program to develop test methods and specifications. This seems to indicate that the concept shows promise. They have a real need for a material that will control cracking. Maintenance of roads and streets at Army installations is a big problem since most of them have far exceeded their economic life. The Air Force is also investigating the use of asphalt-rubber.

At least 23 states have participated in asphalt-rubber demonstrations or test strips. None have implemented asphalt-rubber chip seals, SAM or SAMI as routine replacements for conventional materials. A number of the test strips have not performed well, but most have seemed to fulfill particular needs that have existed. Most failures can be related to lack of experience of the design team or contractor inexperience, and do not necessarily indicate the material itself is not usable.

It is the conclusion of the research team that asphalt-rubber is unique in controlling cracking when used on top of a cracked pavement and then covered with a thin overlay. It is also concluded that asphalt-rubber chip seal can be a successful surface treatment on severely cracked pavements where the only other option seems to be reconstruction, although there is a difference of opinion as to whether chip seal should be used on high-speed roads where loose chips could create a hazard.

Asphalt-rubber has been proven effective in many tests all across the country. Although a complete list of installations is not available, it is believed that 8,000 to 10,000 lane-miles of aspahlt-rubber have been applied. It is also reported that asphalt-rubber has been so successful in the Saskatchewan Province of Canada that its use is routine on low-traffic volume roads.

Although the evidence is strong that asphalt-rubber is a technically proven material, this does not mean that the material is universally acceptable yet for routine applications in the U.S. In fact, many of the 8,000 to 10,000 lane-miles of asphalt-rubber have given disappointing performance. In most cases, this can be related to lack of experience of contractors and engineers, and because there are still many aspects of asphalt-rubber not fully understood. There is a strong need for both additional research and additional availability of trained personnel.

Research Needs

It is clear that there are serious gaps in the information that is available in evaluating asphalt-rubber mixtures for construction conditions (sprayability) and service conditions (durability). As a result, there is a lack of standard tests that are available to measure appropriate properties and specifications are vague on requirements of the asphalt-rubber mixture.

In a presentation at the Asphalt-Rubber Conference, Scottsdale, Arizona, May 1980, the following estimate of research needs were outlined by FHWA:

	Estimated Required Funding-Dollars	Time Estimated Required-Years
Energy requirements for asphalt-rubber and alternatives	100,000	-
Develop end product specifications	1,000,000	2 to 3
Develop design procedures for crack control	1,000,000	2 to 3

The following additional information was suggested by a representative of Texas A&M University at the Scottsdale Conference.

Topic	Estimated Required Funding-Dollars
Optimum Use Conditions	200,000
Summary of Existing Performance	150,000
Standard Performance Information and Data Base	400,000

An expanded list of research topics would include the following:

1. Nature of the physical-chemical reaction between rubber and asphalt.
2. Development of appropriate tests and laboratory equipment for evaluating application and service-related properties.
3. Determination of the temperature susceptibility of various asphalt-rubber mixtures.
4. Determination of the interaction of A-R with aggregate.
5. Evaluate durability and other field performance parameters.
6. Develop design procedures for crack control.
7. Develop better specifications--probably of the performance type.
8. Establish energy requirements and costs--particularly life cycle costs.

The working group on Construction and Maintenance at the Scottsdale Conference emphasized the following problems:

- Lack of knowledge on the part of the designers, supervisory engineers, and construction personnel (control people). There is a need for additional training, probably through a coordinated technology transfer program.
- Lack of coordination between design and materials personnel.

- There was a lack of control on the ADOT projects. There must be an established quality control procedure about which the necessary people are informed.
- There is a need to consolidate the available information.

SPECIFICATIONS

As of late 1980, there have been no standard specifications for use of asphalt-rubber developed by the Federal Highway Administration or AASHTO (American Association of State Highway Transportation Officials) for states and other interested consumers to use for guidance. However, the State of Arizona does have specifications for routine use of asphalt-rubber, and ASTM (American Society for Testing and Materials) has formed a committee to develop guide specifications. Also, many states and localities adopt industry specifications as a supplemental specification. Thus, if a test strip or other limited use is anticipated, approval can be obtained to use a supplemental specification on a limited basis.

Specifications have been developed by both producers and users of asphalt-rubber products. These include both material and construction specifications for chip seal (SAM), and stress absorbing membrane interlayer (SAMI).

The materials that are covered in the specifications are:

- asphalt cement
- rubber extender oil
- ground rubber
- asphalt-rubber blend
- diluent
- cover aggregate
- blotter material

The following examples of specifications are included in Appendix A, Volume 2:

1. Specifications for ARM-R-SHIELD $^{\text{TM}}$, Arizona Refining Company Specification M 101-80, dated 2/80.
2. Construction Specification for ARM-R-SHIELD $^{\text{TM}}$ stress absorbing membrane interlayer, Arizona Refining Company Specification C 208-80, dated 2/80.
3. Construction Specification for ARM-R-SHIELD $^{\text{TM}}$ surface treatment, Arizona Refining Company Specification C201-80, dated 2/80.

4. Guide specifications for asphalt-rubber for stress absorbing treatments (SAM or SAMI), Sahuaro Petroleum and Asphalt Co., dated November 1979.

5. Stress-absorbing membrane (interlayer) and stress-absorbing membrane (seal), Arizona Department of Transportation, dated 8/22/79 and 8/23/79.

6. Specification for ARM-R-SHIELD-CF, Arizona Refining Company specification, dated 1/80.

7. Open Graded Rubberized Asphalt Friction Course, SRL-H (reclaimed), Pennsylvania Department of Transportation, for experimental project in 1979.

These specifications are, for the most part, typically definite in their requirements. Many of them, however, contain statements that reflect the lack of precise methods for controlling the properties of the asphalt-rubber blend.

There are various statements that indicate that the determination of a suitable asphalt-rubber mix is still an art that must be practiced by an experienced expert rather than a science that can be applied by a qualified practitioner.

COST

Proponents of the SAM and SAMI approach to restoring deteriorated pavements claim that the asphalt-rubber chip seal performs a unique function, that of preventing reflection cracking. There is no other established method of doing this effectively that would enable a one-to-one cost comparison to be made. This limitation is further complicated by a lack of well-documented data that would provide a base for life-cycle cost comparison between competing systems. It is clear that many potential users consider asphalt-rubber to be "expensive" as far as initial cost is concerned. Some of these potential users have not been convinced by the available data and evidence of precisely what the long-term economic benefit is. In the present atmosphere of belt-tightening that exists in most state highway departments, first cost considerations are becoming more and more important. In summary: (1) comparing the cost of asphalt-rubber with competing systems is difficult; (2) first cost of asphalt-rubber is high and this could serve as a deterrent to the further development of its use; (3) a reliable data base documenting long-term improvement in pavement serviceability is necessary; and (4) a life-cycle cost analysis is needed in order to address the question of economic benefit.

The following cost information has been developed. The cost of an asphalt-rubber chip seal where the asphalt-rubber is applied at 0.6 gallons per square yard with 40 pounds per square yard of chips is $1.25 per square yard.* The source of this information contains the following introductory statement: A research study has shown that the Arm-R-Shield** surface treatment, followed by a 3/4-inch thick conventional overlay, is as effective, and sometimes more effective, as 4-inches of regular asphalt concrete overlay when it comes to resisting reflective cracking. So, the thinner resultant structure reduces construction costs, even though Arm-R-Shield is more expensive than regular asphalt." A subsequent cost comparison shows that the Arm-R-Shield plus the 3/4-inch overlay would cost $2.59 per square yard, which is $3.16 per square yard less than the $5.75 per square yard for the 4-inch overlay.

Another source estimated that the asphalt-rubber chip seal is equivalent to 1-inch of asphaltic concrete, which would mean between $1.00 and $1.25 per square yard.

The City of Phoenix reported the following costs:

Year	Major Streets*	Residential Streets**	Asphalt-Rubber Chip Seal
1970-71	$0.27 per square yard	$0.24 per square yard	$0.96 per square yard
1979	$0.47 per square yard	--	$1.05 per square yard
1980	$0.67 per square yard	--	Not Available

* 3/8" chips + AR8000 asphalt.
** 1/4" chips + AR4000 asphalt.

This cost history shows the narrowing relationship between the cost of a conventional chip seal and the asphalt-rubber chip seal between 1970 and 1979.

On the basis of eight projects bid in 1978 for the Arizona Department of Transportation, the average cost of asphalt-rubber was $1.12 per square yard. The costs ranged from a low of $0.83 per square yard to a high of $1.45 per square yard.

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* From a cost analysis prepared by Arizona Refining Co. entitled ARM-R-SHIELD, Cuts Resurfacing Cost in Half, Saves Energy, Consumes Old Tires, (see Appendix for the entire analysis).

** Arm-R-Shield is Arizona Refining Company's trade name for the asphalt-rubber mixture.

Thus, it is clear that on a first cost basis, asphalt-rubber chip seals are more expensive than conventional chip seals. However, there is insufficient experience to allow a calculation of life cycle cost at this time, although it is quite possible that the result would be favorable to asphalt-rubber. A cost comparison for SAM or SAMI is quite difficult at this time because of the lack of a conventional material that performs in the same manner. It has not been established whether a SAM or SAMI should be compared to conventional overlay, wether they delay reconstruction, or both. It is clear that by some calculations, asphalt-rubber is less expensive, while others will not agree. Thus, there is insufficient data at this time to determine an accurate cost comparison.

ENERGY AND ENVIRONMENTAL ANALYSIS

The potential energy and environmental effects of procurement guidelines need to be evaluated in terms of their total effect. Any mining, manufacturing, construction or transport activity results in energy consumption, pollution, and damage to the environment. The question to be answered is whether the procurement guidelines will result in more of these undesirable effects or less.

To do this, it is necessary to consider all of the activities related to the end result of interest. Thus, for an asphalt-rubber SAMI, it includes not only the actual laying of the SAMI itself, but also all of the preceding operations. As shown in Figure 7-3, this includes mining, transporting, and processing of aggregates; and drilling, transporting, and refining of oil as well. This must then be compared to comparable operations for conventional materials.

For asphalt-rubber applications, this raises some problems. As discussed previously, asphalt-rubber is unique and does not strictly replace any other material. Thus, any comparisons are of questionable validity. However, for the purposes of highlighting the energy and environmental issues, it is useful to study an example comparison. The comparison here is the two products in Figure 7-3--asphalt-rubber SAMI with 2-inch overlay, and a 4-inch conventional overlay. The unit of comparison is one mile of 2-lane road, 24-feet wide.

Solid Wastes

One of the goals of RCRA is the alleviation of municipal solid waste problems, and it is clear that asphalt-rubber could potentially play a role in the reduction of the tire solid waste problem. As can be seen from Figure 7-3, about 8 tons of tires would be required per mile (2-lane miles). If used only on 250 lane-miles per year in each state,* this would translate to 50,000 tons of recycled rubber per year, or 4.5 million car and truck tires.

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* This is the estimated use level in Arizona at present.

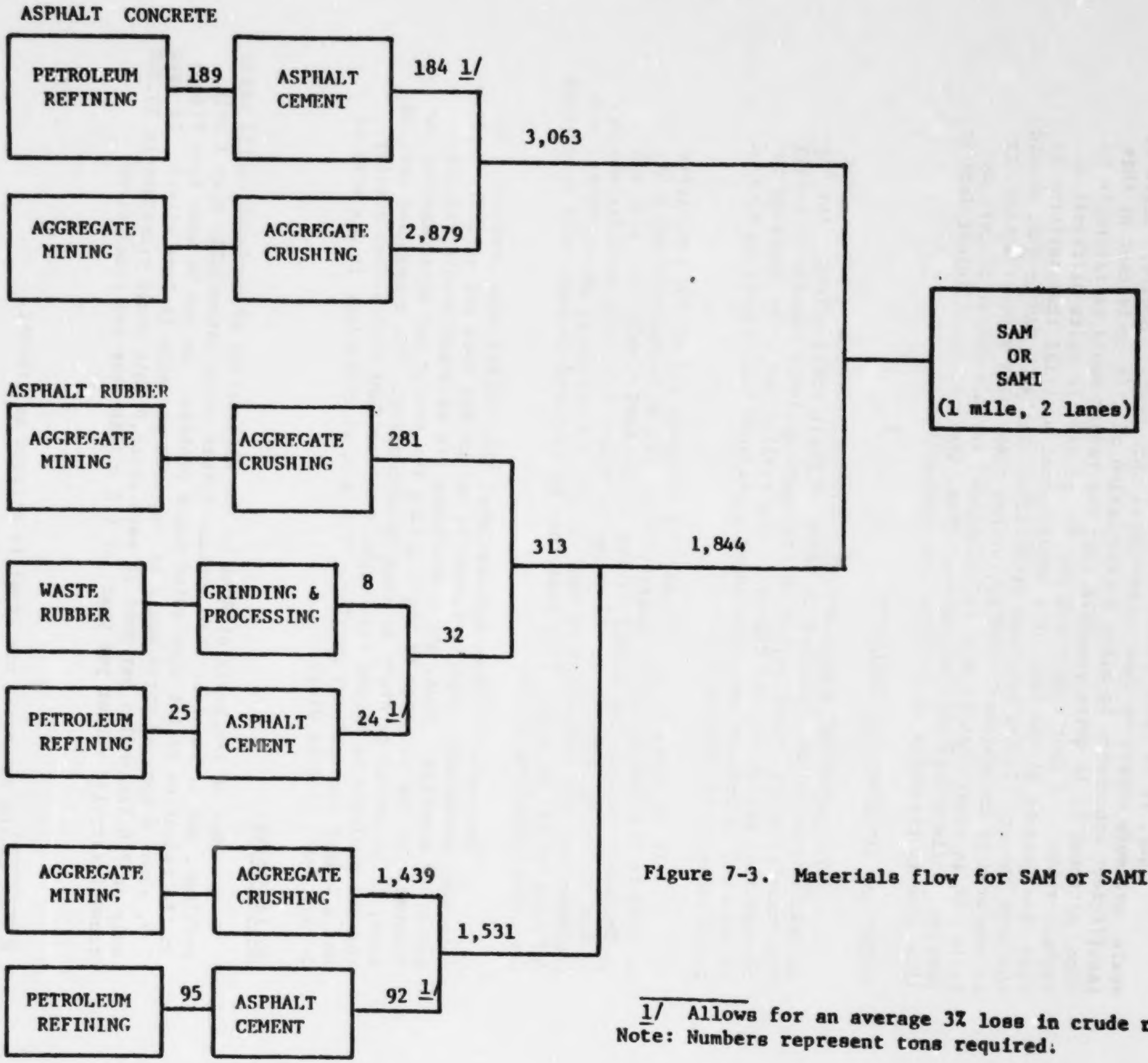
ASPHALT CONCRETE
PETROLEUM REFINING
189
ASPHALT CEMENT
184 1/
AGGREGATE MINING
AGGREGATE CRUSHING
2,879
3,063
SAM OR SAMI (1 mile, 2 lanes)
ASPHALT RUBBER
AGGREGATE MINING
AGGREGATE CRUSHING
281
WASTE RUBBER
GRINDING & PROCESSING
8
32
PETROLEUM REFINING
25
ASPHALT CEMENT
24 1/
313
1,844
AGGREGATE MINING
AGGREGATE CRUSHING
1,439
PETROLEUM REFINING
95
ASPHALT CEMENT
92 1/
1,531

Figure 7-3. Materials flow for SAM or SAMI (tons).

1/ Allows for an average 3% loss in crude refining.
Note: Numbers represent tons required.

It is not possible to project future use of asphalt-rubber because its usefulness and full application potential have not yet been determined. If its application in maintenance and resurfacing were to become universal, the potential for use is quite large. In 1978, 210 million tons of asphalt hot mix were used in this application, perhaps using 12.6 million tons of asphalt cement. If 25 percent of asphalt cement were replaced by rubber tires, the consumption of rubber would be over 3 million tons of rubber, which is more than the total annual quantity of tires disposed of.

Previous calculations gave a range for the potential impact on the waste stream of between 50,000 tons up to all tires disposed annually. At the low end is the potential for significant landfill savings for localities located near major supply points, perhaps even completely eliminating the problem for some large cities. At the high end, it would represent an impressive step towards elimination of a national problem. In any event, the use of asphalt-rubber clearly has a desirable environmental impact from the municipal waste point of view.

Industrial processing also inevitably produces some solid wastes. For the systems being considered here, the significant processing solid wastes are those generated in aggregate mining and crushing. These are mineral wastes, which are not normally considered hazardous to health, and are generally readily disposed of. There is also a significant solid waste associated with coal used directly as a heating fuel, or indirectly as a fuel to produce electricity. The waste is associated with coal mining and processing, and is not as innocuous as aggregate wastes. Because the coal waste has a high carbon content, the waste piles frequently undergo spontaneous combustion and smolder for years, defying attempts to permanently smother the combustion. Adverse environmental effects associated with coal wastes include hazardous water pollution from acid runoff, persistent air pollution as well as detrimental aesthetics.

Owing primarily to the lower demand for aggregates, asphalt-rubber results in nearly 2,000 tons less processing wastes than for conventional asphalt concrete for each mile of 2-lane road.

Energy

Detailed calculations for the energy required in each step shown in Figure 7-3 are found in Appendix D, Volume 2. The total energy for each product is shown in Table 7-5. As can be seen, the asphalt-rubber requires significantly less energy than conventional asphalt concrete. This is because for the conventional asphalt system diagrammed in Figure 7-3, crude oil production and transport and asphalt cement production account for 77 percent of the energy. Thus, replacing the energy-intensive material with tires, which are less energy-intensive, results in significant savings.

Table 7-5

STRESS ABSORBING MEMBRANE INTERLAYER (SAMI) ALTERNATIVES
(One mile of 2-lane road)

	Asphalt Concrete	Asphalt-Rubber
Energy (10^9 Btu)	9.1	5.9
Air Pollution (10^3 lb)	39.9	25.1
Water Pollution (10^3 lb)	3.5	2.3
Processing Solid Wastes (10^3 lb)	5.2	3.4
Materials Derived from Waste (10^3 lb)	0	16

Source: Franklin Associates, Ltd.

An important point here is that the energy content of the asphalt itself is included. Franklin Associates has determined by contacting petroleum refineries that asphalt cement is diluted and sold as a fuel oil if it is not sold as asphalt cement. Thus, its use in highway construction results in the removal of a fuel from the world's finite fossil energy inventory, just as if it had been burned. Thus, in terms of the impact on future energy supplies, there is no difference as to whether it is used as asphalt cement or as a fuel oil. This is an important assumption. Reference to Appendix D shows that if the fuel content of the asphalt is subtracted out, then the energy for the asphalt concrete option is 2.4 x 10^9 Btu, while the energy for the asphalt-rubber option is 3.4 x 10^9 Btu. Thus, under these assumptions, asphalt-rubber would require more energy, because it requires more energy per pound to grind and process tires than it takes to refine crude oil in asphalt cement.

Air Pollution

The SAMI and conventional asphalt systems were analyzed in terms of five major air pollution categories. By far the largest amount of air pollution produced is in the form of particulates. While all operations generate some particulates in the form of "smoke" from fuel combustion, the dominant production is dust from aggregate mining and crushing. As shown in Table 7-5, nearly 40,000 pounds of air pollution are produced by the asphalt concrete system, and only 25,000 pounds by the asphalt-rubber system. For the asphalt concrete system, nearly 26,000 pounds of this are particulates. Over 4,000 pounds of nitrogen oxide and 5,700 pounds of hydrocarbons are produced from fuel combustion in the various processing and transport operations, with 2,200 pounds of sulfur oxide and 1,700 pounds of carbon monoxide resulting primarily from oil refining to produce asphalt, and fuel combustion for the various processing and transportation steps.

Thus, because asphalt-rubber options reduce the amounts of aggregate needed, nearly 15,000 pounds of air pollutants are avoided for each mile of road constructed if asphalt-rubber is used. Therefore, the potential for air pollution reduction is significant.

Water Pollution

The quantity of pollutants discharged to water is small compared to air pollution discharge for highway construction products. For the seven water pollutants included in this analysis, 94 percent by weight for the asphalt concrete system was dissolved solids. This is primarily related to asphalt, but also to the petroleum-based fuels that are used in every step. In any event, the substitution of the asphalt-rubber system for asphalt concrete in our comparison will result in over 1,000 pounds less of water pollution per mile of 2-lane road.

Summary

From Table 7-5, it is clear that asphalt-rubber used as a substitute for asphalt concrete results in less energy and environmental impact in every category. Thus, it is concluded that use of asphalt-rubber is desirable from that point of view, at least to the degree that our example as shown in Figure 7-3 is realistic. Although it is probable that asphalt-rubber in similar applications would lead to desirable energy and environmental impacts, each application category would need to be analyzed separately for a reliable conclusion.

GUIDELINE OPTIONS

Introduction

There is a broad range of guideline options available to EPA. The two extreme options would theoretically be no guidelines at all, or mandatory guidelines that would require fixed minimum amounts of recovered materials. These two theoretical extremes are discussed in Chapter 3. Between these two extremes are a number of plausible options, which are presented and analyzed in this section.

In the material which follows, a brief summary of the conclusions reached in this chapter is presented, followed by an analysis of five guideline options. Those options are: 1) dual bids; 2) increase and improve educational activities; 3) increase funding for research and testing; 4) use of grants, bonuses, or other financial incentives; and 5) delay of guideline implementation. Advantages and disadvantages of each option are presented, but no option is singled out for recommendation by the authors.

Conclusions

The conclusion based on the preceding analysis is that asphalt-rubber is a highway construction material which has proven merit. It is clear that some asphalt-rubber chip seals and SAMI applications have performed satisfactorily in all geographical regions of the U.S. However, it is also clear that there are many installations which have performed poorly. One apparent reason for this is that the chemical and physical reactions between asphalt and rubber are not completely understood. It also appears that an important factor in installations that have performed poorly is the lack of adequate experience in use of the material.

Perhaps the most important factor in repeated successful applications of asphalt-rubber is persistence in learning how to best manufacture and use the material in a particular geographical area. In Arizona and the Canadian Province of Saskatchewan routine success is now achieved with asphalt-rubber. In both cases, certain individuals have carefully studied successes and failures in their respective areas, and have persisted in solving the problems that resulted in failures.

Much progress has been made in solving problems all across the country in recent years, but many state departments of transportation are reluctant to specify use of asphalt-rubber because of technical uncertainties. In many cases, states have installed test strips which are presently under evaluation, but they will not proceed with routine use until they are convinced that the reliability of successful use is high.

Perhaps a key factor in the lack of persistence in some states is economics. In many cases, total cost of application of asphalt-rubber exceeds that of conventional materials. Although in some cases asphalt-rubber had been shown to last up to twice as long as conventional materials (in chip seal applications), there are not yet sufficient data to be convincing in many cases. However, two factors are presently at work which may at some point in the near future enhance the economics of asphalt-rubber. One factor is that when sufficient asphalt-rubber test strips have completed long term tests, the results may show that they routinely have much greater durability than conventional materials. The other factor is that there has apparently been a trend in recent years which has resulted in a narrowing of the difference in initial costs of asphalt-rubber and conventional materials. If that trend continues, the economics of use of asphalt-rubber will steadily improve.

Dual Bids

One guideline option available to EPA is to require that in certain applications asphalt-rubber must be specified as one possible material. For example, perhaps it could be specified for severely cracked pavements. Thus, if a chip seal is to be applied, the procuring agency must stipulate that either a conventional asphalt or asphalt-rubber should be bid.

This dual bid would take one of several forms depending on state laws. In some states, the appropriate form would be as an alternate bid. When this mechanism is used, the bid document instructs the bidder that their bid must be for either asphalt-rubber or for the conventional material. Thus, the choice of material is fixed at the time of contract award, and the winning contractor uses the material that he chose when preparing his bid.

In some states the mechanism used is an optional approach. In that form, the contract is awarded before the material choice is made. That is, the job is bid at a certain price, and the contractor agrees to select one of the optional materials at a later time. Then, when construction begins, the contractor exercises his option to decide which material will be used, which usually is the material which results in the least cost to him at that time. However, some provision would need to be made for states which do not have specifications for routine use. In some states where tests have already been made and evaluated, this may only require a year. However, in states where tests are not completed it may require as much as five years. At present, only two states have specifications for routine use--Texas and Arizona, so most states would require additional time.

Advantages. The advantage of the dual approach is that recovered material use is encouraged, but not required. If a contractor wants to use asphalt-rubber and feels that he can be low bidder by so doing, this opportunity is available to him. The dual bid approach is a strong approach in that it requires procuring agencies to become knowledgeable about asphalt-rubber and to specify which applications are most suitable for that product. It insures that competition will be maximized by allowing contractors to bid conventional materials or asphalt-rubber. Thus, no potential contractors are excluded from the competition because of a material requirement. This procedure also insures that the material will be readily available, because contractors will not bid a material for which this uncertainty exists. Finally, the dual bid approach insures that products are purchased at the least cost to the procuring agency because of the competitive bid situation.

Disadvantages. There are several disadvantages to dual bids for asphalt-rubber. Perhaps the most important one is that it does not seem clear that asphalt-rubber and conventional asphalt would be considered for the same job. One result of the analysis is that asphalt-rubber has unique properties, particularly with regard to its ability to retard cracking. Thus, if asphalt-rubber is viewed as having unique properties, jobs would be designed specifically for asphalt-rubber and no alternatives would normally be allowed. However, in states where chip seals are used, it is likely that dual bids would be feasible for that application.

Another problem with dual bids for asphalt-rubber is the current perception by many procuring agencies that asphalt-rubber is not cost competitive. It is clear from our data that asphalt-rubber chip seal has a higher installed cost than conventional chip seal. Thus, in a dual bid, asphalt-rubber would likely never be selected because it would likely always be higher in cost. Proponents of asphalt-rubber maintain that superior performance of asphalt-rubber will lead to lower life cycle costs. However, little is known about life cycle costs due to a lack of test strips which have been evaluated for sufficient time. Also, at present, life cycle costing has not been made a feature for consideration in most competitive bids so that its consideration is not always possible.

Another problem with dual bids is that it will not be successful in stimulating use of asphalt-rubber where procuring agencies do not believe it is an acceptable material. The dual bid procedure can be easily circumvented by writing some provision into the specification that will insure that asphalt-rubber would never be cost competitive. These acts, which may be based on a covert attempt to avoid use of a material, are difficult to identify and correct, because experimental data may be cited which support their position. The extremely wide variations in composition and quality of construction materials available in a given place, along with extreme variations in climate, soils, and other environmental conditions, make independent judgment of design specifications difficult.

Dual bids may also cause an inconvenience in many locations where asphalt-rubber does not ever win bids. In some locations asphalt concrete is quite inexpensive, and in those areas asphalt-rubber would likely never be the low bid. Thus, any rule requiring dual bids would result in unnecessary work for the procuring agency. In many states, dual bids result in the necessity of preparing separate designs for each material. In some states this is a minor problem. In others it is considered a major problem. In any event, if asphalt-rubber never wins bids, any extra effort to prepare a dual bid would be considered as wasted effort by the procuring agency. Because almost all states do not presently have a specification for routine use, as chip seal or SAMI, this guideline option would have to have a delayed implementation. Under normal circumstances, few states would be able to prepare specifications for routine use in less than three to five years, although if guide specifications would be prepared by FHWA, AASHTO, and/or ASTM it would seem to reduce the time need by the states to develop their own specifications. However, specifications can be prepared in a short time for demonstration projects, and these specifications can normally be used as an interim specification.

Increase and Improve Educational Activities

A guideline requiring dual bids places requirements on direct Federal procurements, and to a much greater extent places a requirement on state and local highway construction procuring agencies. An alternate to this approach is to put more of the responsibility on the Federal government. One way of doing this is to require that the Federal Highway Administration (FHWA) increase and improve their educational activities.

It is clear that at the headquarter level in Washington, D.C., FHWA has done much to promote and encourage the use of asphalt-rubber by disseminating educational materials to the FHWA regional offices. However, from the interviews with the states, it is clear that most district level FHWA engineers have not promoted the use of asphalt-rubber. Thus, the focus of this activity would be to insure that FHWA district engineers in every state are well trained in the use and new developments of asphalt-rubber. In turn, they should make state departments of transportation officials aware of the importance of use of recovered materials as a national policy and of the importance for each state to seriously study the potential advantages of use of asphalt-rubber within the state. Dissemination of information and conducting training sessions for state district engineers should be encouraged. Perhaps key states could be targeted for this activity initially.

FHWA has recently increased activity in this area. Thus, EPA should remain current on the present status before implementing guidelines.

Advantages. An advantage of this guideline is that it does not require immediate or precipitous use of asphalt-rubber and therefore will insure that its use can be more carefully evaluated by each procuring agency. It also would be a wiser approach from the point of being less "heavy handed" with regard to the states by not placing requirements for dual bids on them. However, it should increase the awareness of asphalt-rubber and would likely result in more use of asphalt-rubber.

Disadvantages. A disadvantage of this guideline option is that it may result in less immediate use of asphalt-rubber than a dual bid guideline. Also, it will require expenditures on the part of FHWA to provide a staff to implement this activity. Because of a generally tight budget situation, this may cause some difficulty for that agency.

Another advantage is that in some cases district engineers will ignore these guidelines to the extent possible; in other cases, they may be overzealous and place undue pressure on states to use recovered materials to the extent that they would be used in inappropriate applications. Either of these types of actions would be contrary to the intent of the guidelines.

Increase Funding for Research and Testing

Because the best applications for asphalt-rubber are to some extent still in doubt, and because basic chemical and physical reactions are not well understood, FHWA could make asphalt-rubber a priority research item. In an earlier part of this chapter (page 7-16), the priority research and testing needs are listed.

Advantages. An advantage of this guideline option is that it would lessen the time until asphalt-rubber is better understood. This would increase the user's ability to wisely incorporate asphalt-rubber in road construction and increase the reliability of installation. This would enhance its salability and lead to wiser use. Also, it would focus on the merits of utilizing asphalt-rubber in maintenance activities. In the near future, maintenance activities will become more and more important to highway departments as new construction declines and existing roads continue to deteriorate.

Disadvantages. The main disadvantage would be that FHWA would likely have to divert research funds from other projects which they have identified as being more important. Thus, a basic policy decision would need to be made that it is more important for FHWA to conduct research alleviating the solid waste problem than to fund additional research for asphalt-rubber solely on its merit as a highway construction material. FHWA has already made its judgment with regard to the merits of asphalt-rubber based on research that has already been done, and this guideline would essentially require them to alter those decisions in favor of funding more research on asphalt-rubber.

An alternative may be additional funding by Congress for these activities. If use of recovered materials is deemed to be in the national interest, this would be justification for increasing the FHWA budget in order to fund these activities.

Another disadvantage of this guideline is that the payoff would be slow. The problems with asphalt-rubber that require additional study may not be easily resolved, and a number of years may be required for definitive answers.

Use of Grants, Bonuses, or Other Financial Incentives

A way to encourage procuring agencies to use more asphalt-rubber is to use financial incentives. This could take many forms. It could include block grants to states to use asphalt-rubber, or to experiment with its use. Another option would be to grant a bonus on projects using asphalt-rubber. For example, if the normal Federal share of a particular road were 70 percent, a state could be granted a bonus to use asphalt-rubber on the roadway and receive a greater Federal share, say another 5 percent to 75 percent for the portion of the project where asphalt-rubber was used.

Perhaps this program could be implemented as an extension of current FHWA demonstration programs, where financial incentives are offered to states for first time installation of demonstration or test sections.

Advantages. This would be one of the most rapid ways in which to increase the use of asphalt-rubber. A serious problem facing virtually all highway construction entities is a shortage of funds. Providing money for roadbuilding and maintenance in any form would be met with a more positive response than any other option by the highway construction industry.

Disadvantages. The most serious disadvantage to this guideline would be the locating of funds. FHWA administers the Federal funding of highway construction projects, and they are suffering a severe erosion of funds which can be used for highway construction. Therefore, a basic policy decision would have to be made that money could be diverted from other uses for the purpose of funding these guideline options. However, as discussed previously, an alternative would be for Congress to increase funding levels because use of recovered materials is deemed to be in the national interest.

Another major disadvantage is that this guideline would encourage the indiscriminate use of asphalt-rubber to obtain the additional road building funds. Thus, careful monitoring would have to be exercised by FHWA to insure that asphalt-rubber is used in the proper applications. For example, FHWA may have to develop specific guidelines for use such as specifying a level of deterioration of a roadway which would have to be reached before asphalt-rubber use would be supported. In some states there already exist quantitative measures of pavement deterioration, called pavement condition ratings, so development of guidelines is possible.

Another potential problem with this guideline option is that it is possible that the legal problems would not permit certain kinds of financial incentives, thus requiring additional legislation. These would have to be carefully investigated.

Delay Guideline Implementation

A final guideline option is to delay implementation of a specific guideline option for a specified number of years. For example, EPA could publish their intent to implement a dual bid guideline in 5 years.

Advantages. An advantage of this option is that it would delay definite action in view of the fact that there are still many unknowns concerning the use of asphalt-rubber. In 5 years, hundreds of test strips that have been placed will have been more completely evaluated, and the picture on how and where asphalt-rubber should be used will be clearer. In addition, a formal notice by EPA of the intent to implement a guideline for asphalt-rubber would give procuring agencies time to develop specifications and to plan for the best use of the material and how best to comply with the guidelines.

Disadvantages. The primary disadvantage of this option is that it would delay any definitive action by EPA and would delay any possible benefits of the guidelines.

Chapter 7

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Chapter 8

USE OF INCINERATOR RESIDUE IN HIGHWAY CONSTRUCTION PRODUCTS

INTRODUCTION

Construction of incinerators for municipal waste disposal in this country began in the late Nineteenth Century, but few were built prior to 1950. Following World War II, there was a significant increase in the number of incinerators constructed as the economy rebounded from the war and a sharp increase in solid waste occurred. Most of the incinerators built at that time were of a small capacity, i.e., 100 to 200 tons per day units.

However, in recent years, many incinerators have been closed due to operation and maintenance costs, including the large investments required for air pollution controls. This has come about by more stringent governmen control of the incineration processes through regulation of air quality and solid waste disposal. The escalating costs of the required environmental control equipment in many cases does not warrant the upgrading of smaller capacity plants to meet specifications.

Incinerators being constructed today can typically handle quantites of refuse in the 1,000 to 1,500 tons per day range. The economy of scale for the larger plants allows the economic construction of pollution control devices, especially when the escalating cost of the alternative forms of disposal, especially landfilling, are taken into account. In the new, larger volume plants, energy recovery and selective materials recovery are also important considerations.

In this country, at least 90 percent of the municipal waste stream is landfilled as a means of final disposal. However, landfill closings have become increasingly frequent as the waste stream grows and existing sites are filled to capacity. When this occurs, many municipalities are faced with very difficult choices for disposal of the wastes. New landfills are usually difficult to open because of problems in finding suitable sites. One option is to incinerate waste, which can extend existing landfills for many years by greatly reducing the volume of the waste. However, incinerators produce residues which must be disposed of, and use of this residue is an additional factor in extending landfill life. In this chapter, the potential for using incinerator residue as a highway construction product is discussed.

INCINERATOR RESIDUE GENERATION AND RECOVERY

All incinerators do not handle and process refuse in the same manner. The basic differences, in refuse processing within the incinerator plants, occur with the feeding and supply of refuse to the furnace, and the type of furnace itself.

The four types of furnaces used for municipal solid waste refuse are: vertical circular furnaces; rectangular furnaces; multi-celled rectangular furnaces; and rotary kiln furnaces. These furnaces may be either batch fed or continuous fed.

A grating system transports the refuse and residue through the furnace. The types of grates currently used in refuse processing may be described as traveling, reciprocating, rocking, rotary kiln, circular, vibrating, oscillating, or reverse reciprocating.

In combination, the important variables which affect the quality of the residues produced (well burned as opposed to poorly burned) are time of combustion, temperature of combustion, and the turbulence during combustion. It is noted that the different types of grates are somewhat correlated to the quality of the residue produced. As an example, better burnout may be achieved due to the better agitation action of the refuse on the rocking grate than on a traveling grate.

A classification system for the residue has been developed which identifies six basic categories of residue according to degree of burnout. These classes are: ultra-well burned out residues; well-burned out residues; intermediately burned out residues; poorly burned out residues; residues with especially low metal content; and pyrolysis residues. In general, these six categories may be related to basic plant design. Well burned residues are usually produced from refuse that is transported by agitating type grates (i.e., rocking, reciprocating). Intermediately burned residues are usually produced on well operated traveling grates. Poorly operated traveling grates and batch fed furnaces will usually produce a poorly burned residue.

Low percentages of combustible material are found in well burned residues, and very low percentages of combustible materials are found in pyrolysis residues. High percentages of glass are also found in pyrolysis residues.

Municipal refuse is quite variable in nature. Composition of the mixed waste stream will vary greatly from place to place, and also vary greatly from time to time at a single location. The peak months for mixed waste is in the spring, when there are large amounts of yard waste being generated as well as residues from "spring cleaning" and also from high consumption of products. The low point is typically in January, when only 50 to 75 percent as much waste is available for incineration as in the spring.

Incinerator residue is primarily composed of glass, metals, minerals, ash, and unburned combustibles. The percentages of its components are not subject to as large a variation as in the total waste stream, because the most variable portions are combustible. A representative average approximation of percentages by weight of the residue components is as follows (Reference 8-1).*

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* See references at the end of the chapter.

Glass	48 percent
Metals	18 percent
Minerals and Ash	21 percent
Combustibles	13 percent
	100 percent

Incinerator residue is also fairly uniform with respect to particle size distribution, if all the oversized materials (such as appliances) have been initially removed. Nearly all residue is able to pass through a 3-inch screen. Approximately 70 to 90 percent of the residue by weight can pass through a 1-1/2-inch screen (38 mm). The material passing this screen can usually conform to existing gradation specifications for asphalt concrete base course aggregate.

An additional property of significance with respect to incinerator residue (other than physical composition and material grain size) is moisture content. The moisture content of residue varies greatly. Residues that have been freshly quenched with water contain a high moisture content. The water content of as received residues in one study varied between 28 percent and 47 percent (Reference 8-1). However, it has been observed that residues that have been stockpiled for a period of time contain a much lower moisture content than non-stockpiled residues.

It has been recommended in a recent report (Reference 8-1) that only well burned or intermediately burned incinerator residues should be considered for use in highway construction. This same report recommended that residues for construction be stockpiled for several months prior to use; and that a loss on ignition test value of greater than 10 percent of the residue, would deem the residue undesirable for highway construction.

With respect to the residues produced by resource recovery and reclamation plants, only some of the residues may be used for roadway construction materials. The determination of what residues from which plants can be used, should be made on individual and specific application criteria. Some resource recovery facilities produce a synthetic type fuel which is similar in consistency to peat moss. With all the pre-separation and screening involved to produce this fuel, the residue characteristics are appreciably altered. Residues produced, often do not contain acceptable amounts of desirable components (for construction applications) such as glass, and often contain appreciable amounts of undesirable components which may be considered as hazardous. The residues from these recovery facilities may be unacceptable as an aggregate replacement in highway construction applications not only from a structural point of view, but may also be undesirable for public health reasons.

GENERATION OF INCINERATOR RESIDUE

National Generation

In 1978, it is estimated that 150 million tons of residential and commercial postconsumer waste was generated (Reference 8-3). Of that amount, nearly 12 million tons was recovered for reuse or recycling, leaving 138 million tons available for incineration. Less than 10 million tons is incinerated annually, with an estimated generation of 2.0 million tons of residue.

This waste generation is smaller than for the other materials considered in this report. Power plant ash generation was estimated at 75 million tons per year, kiln dusts at 10 to 14 million tons, and rubber tires at nearly 4 million tons annually. Thus, incinerator residue is not presently a serious problem in terms of national generation, nor does it cause any special disposal problems such as rubber tires. In terms of overall national impact, incinerator residue is probably the least serious problem of the four categories of waste materials considered in this study. However, incinerators are generally located in large metropolitan areas which face serious waste disposal problems, thereby presenting a severe impact in selected locations.

In addition, the possible future rapid growth of resource recovery installations may result in a rapid growth of incinerator residue. In the late 1960s there were nearly 300 incinerators operating at one time, but by 1975 this number was reduced to 140, and at the present time there are only 60. If this trend continued, there would be little incinerator residue available in the future. However, a counter trend is rapidly developing because of the appearance of resource recovery incinerators. In 1977, nearly a million tons of waste was being produced in resource recovery incinerators, resulting in an estimated 200,000 tons of residue (Reference 8-4). This included four modular incinerators, five mass burning waterwall units, and four refuse-derived fuel installations. By 1980, there were nine mass burning waterwall units, two refuse-derived fuel installations and nine modular incinerators on line processing 1.7 million tons of waste and generating 320,000 tons per year of residue.

It is widely thought that in many areas the growing crisis in solid waste disposal will result in a rapidly accelerating implementation of resource recovery incinerators. However, that industry has had a history of serious problems in successful operations of economic installations. Projections of growth have been notoriously overestimated as the list of failures lengthens. Thus, at this time, it is difficult to estimate how long it will be before resource recovery incinerators produce sufficient residue to become a problem of national importance. One projection (Reference 8-4) puts the incinerator residue generation at 4 million tons by 1990. At this point, that projection seems overly optimistic, but yet there is the potential for generating those quantities of residue before the end of this century. Thus, allowing for some old incinerator closings, the total incinerator residue in 1990 could be 4 to 5 million tons per year. Use of this material in highway construction products could become quite important in large metropolitan areas.

Geographical Generation Patterns

Incinerator residue is generated in localized areas in the U.S. as shown in Table 8-1 and Figure 8-1. About one-quarter of the residue is generated in New York State, mostly in the New York City area. Two-thirds is generated in six states--New York, Illinois, Michigan, Massachusetts, Maryland, and Pennsylvania. Thus, the geographical generation pattern is concentrated and confined to locations where expensive landfilling situations have eliminated most municipal waste management solutions except incineration.

Current Use Patterns

At the present time most incinerator residue is taken to landfills. Basically, unfused incinerator residue can be minimally processed and used as a low-grade aggregate in highway construction. It can be used as an aggregate in bituminous pavement mixtures as well as in stabilized base materials. Incinerator residue has been tested for applications other than direct roadway usage. This testing includes incinerator residue as a structural fill, as a soil cover substitute in a lined sanitary landfill, as a soil stabilizer, and in portland cement concrete. Incinerator residue has also been used as a wearing surface on "off highway" trails (i.e., bicycle and foot paths). Fused residue in which unfused residue is subjected to intense processing, including a two-step melting process, is usable only in wearing surfaces.

In portland cement concrete mixes, a volume of expansion of the material is caused by the reaction of the aluminum in the residue and the cement in the mixture. Accompanying this volume expansion is a loss of strength. In these mixes, high strengths are not attainable (even where the same proportions of aggregate and residue are used) as the inherent strength of the residue is a limiting factor.

Lime slurrying of the residue can eliminate some of the aluminum cement reaction, but compressive strengths comparable to those of conventional mixes are still not achieved. Pyrolysis residues in portland cement concrete have better strength gains than the other types of incinerator residues in these mixtures.

In use as a fill material, the leachate from incinerator residue is considered as a potential negative factor. Incinerator residue does compact well though, and can serve as an adequate fill material.

Although the amounts of incinerator residue used in each of these applications has not been tabulated, it is clear that the amount is insignificant. It is probable that the amount being used in all of these applications is considerably less than 100,000 tons per year, perhaps even less than 10,000 tons per year. At this time there are no known routine incinerator residue use applications, and what use exists is for experimental purposes.

Table 8-1

NUMBER OF OPERATING PLANTS AND QUANTITIES OF RESIDUE BY STATE

	Number of Operating Plants	Quantity Produced (TPY)
EPA Region 1		
Massachusetts	5	273,000
New Hampshire	1	5,000
Connecticut	6	186,500
Maine	0	0
Rhode Island	1	17,500
Vermont	0	0
Total	13	482,000
EPA Region 2		
New York	13	643,800
New Jersey	0	0
Total	13	643,800
EPA Region 3		
Pennsylvania	3	185,200
Maryland	2	116,000
West Virginia	0	0
Virginia	3	77,900
District of Columbia	1	112,500
Delaware	0	0
Total	9	491,600
EPA Region 4		
Kentucky	1	75,000
Tennessee	1	63,000
North Carolina	0	0
South Carolina	0	0
Mississippi	0	0
Alabama	0	0
Georgia	0	0
Florida	3	41,300
Total	5	179,300
EPA Region 5		
Minnesota	0	0
Wisconsin	2	33,000
Michigan	3	165,000
Illinois	3	177,300
Indiana	1	17,500
Ohio	4	131,200
Total	13	524,000

Table 8-1
(continued)

NUMBER OF OPERATING PLANTS AND QUANTITIES OF RESIDUE BY STATE

	Number of Operating Plants	Quantity Produced (TPY)
EPA Region 6		
Texas	0	0
New Mexico	0	0
Oklahoma	1	5,000
Arkansas	1	8,800
Louisiana	1	15,000
Total	3	28,800
EPA Region 7		
Kansas	0	0
Missouri	2	80,000
Iowa	0	0
Nebraska	0	0
Total	2	80,000
EPA Region 8		
Montana	0	0
North Dakota	0	0
South Dakota	0	0
Wyoming	0	0
Utah	1	39,400
Colorado	0	0
Total	1	39,400
EPA Region 9		
California	0	0
Nevada	0	0
Arizona	0	0
Hawaii	1	52,500
Total	1	52,500
EPA Region 10		
Washington	0	0
Oregon	0	0
Idaho	0	0
Alaska	0	0
Total	0	0
U.S. GRAND TOTAL	60	2,521,400

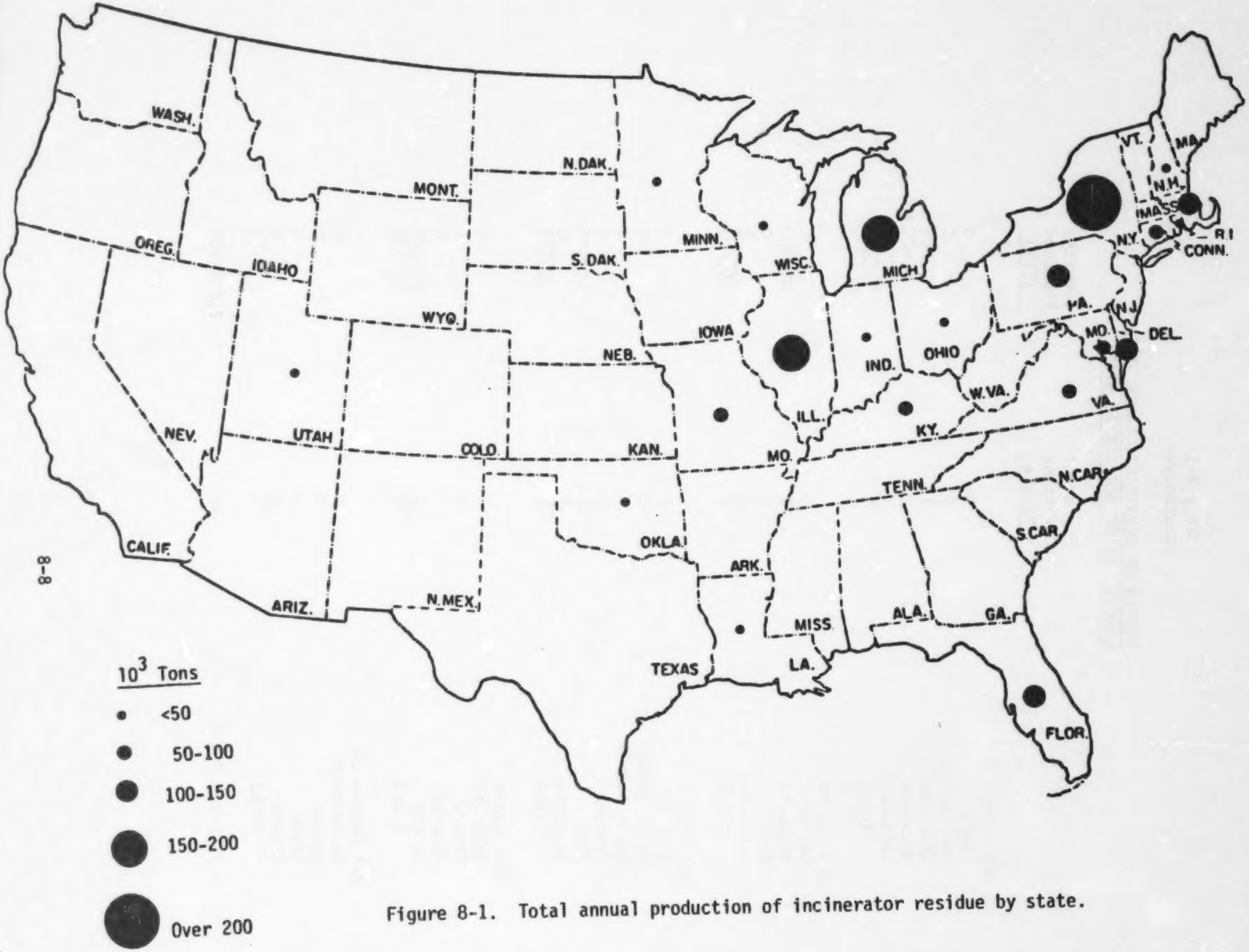
WASH.
OREG.
CALIF.
NEV.
IDAHO
MONT.
WYO.
UTAH
ARIZ.
COLO.
N.MEX.
N.DAK.
S.DAK.
NEB.
KAN.
OKLA.
TEXAS
MINN.
IOWA
MO.
ARK.
LA.
WISC.
ILL.
MICH
IND.
OHIO
KY.
TENN.
MISS
ALA.
GA.
FLOR.
S.CAR.
N.CAR.
VA.
W.VA.
PA.
N.Y.
N.J.
MD.
DEL.
VT.
N.H.
MA.
MASS
R.I
CONN.
10³ Tons
● <50
● 50-100
● 100-150
● 150-200
● Over 200

Figure 8-1. Total annual production of incinerator residue by state.

TECHNICAL ASSESSMENT

An examination was made of three potential highway construction applications of unfused incinerator residue. They are: 1) bituminous base course; 2) wearing surface; and 3) stabilized base and sub-base. In all cases, incinerator residue was used as an aggregate, usually in a mixture of conventional aggregate and incinerator residue. That is, it is not a pozzolanic material and its reactivity is quite low. A complete and detailed technical assessment may be found in Part IV, Volume 2. That material is summarized in the following pages.

Laboratory Investigations

A number of laboratory investigations have been made of unfused incinerator residue in the applications studied. Generally, these investigations have been made in order to develop mix designs for field test applications. One of the most important features of an incinerator residue is the gradation of particle sizes, and the laboratory work has carefully evaluated this. In order for a construction product to perform successfully there must be a wide range of aggregate sizes included, ranging from very fine material (dust) which has a particle size well under 0.1 millimeter to gravel size pieces as large as one-half inch.

One important factor associated with this gradation is that the amount of asphalt cement required in a bituminous mix must be adjusted accordingly. If too many fine particles are present in an aggregate, the consumption of asphalt cement goes up. This is because a ton of fine particles has a much greater surface area than a ton of coarse particles. Thus, for the asphalt cement to coat each particle, greater amounts are needed for fine aggregate.

It has been found that in most cases, incinerator residue requires more asphalt cement than conventional aggregates. While a conventional bituminous mix may be 4 to 5 percent asphalt cement, when incinerator residue is used the asphalt cement required may be 8 percent or higher in order to achieve optimum particle coating. Thus, the asphalt cement requirement may double if incinerator residue is used.

Nevertheless, laboratory investigations reported in Part IV, Volume 2, show clearly that acceptable mix designs can be developed. The tests show that in a number of laboratory tests, properly designed products can meet or exceed all specified performance criteria. Thus, laboratory tests show that highway construction products using incinerator residue can be used as suitable replacements for conventional materials.

Field Tests

In Part IV, Volume 2, a complete description is given of 11 field tests where incinerator residue was used. These installations are summarized in Table 8-2. An initial problem encountered with using incinerator residue in pavement applications is that a great amount of material quality control is needed. This is because only high quality residues may be used in pavement applications. The problem of having to carefully monitor the residue which is to be used in pavement applications arises from the incineration process itself. As previously mentioned, the factors affecting the quality of the residue are time of combustion, temperature of combustion, and turbulence during combustion. Although these three factors are normally of minor concern during municipal incineration operations, they greatly affect residue quality.

An example of this type of uncontrolled combustion is evidenced by the procedure which may occur at an incineration facility having more than one furnace. If the facility operates two furnaces at a certain incoming volume of refuse and is subsequently only able to operate one furnace due to breakdown or maintenance, all of the refuse would be cycled through the single operating furnace. The channeling of the refuse through the single unit would produce a residue of poorer quality than that produced by dual furnace combustion because of faster grate speeds and less than optimal combustion. Also, in municipal refuse processing, variations in seasonal quantities and incoming moisture contents of refuse are not taken into account during combustion operations.

Another problem in producing a residue material to be used in construction applications, is that stockpiling is necessary to produce the necessary quantities required. In conjunction with stockpiling, screening, shredding or trommeling of residue may have to be done as a means of preparing the residue to a desired gradation.

Incinerator residues, however, can be used in pavement applications if properly prepared. An advantage of using incinerator residue in base, sub-base, and wearing surfaces is that it may be placed with conventional equipment. Placement of materials on various jobs have been performed with conventional paving equipment, dump trucks, hand raking, and standard compaction rollers. Another advantage is that the residue material is also easily mixed and handled in the field. Mixing techniques of lime in the residue on different base and sub-base projects varied from handraking to pugmill mixing. The addition of lime to the residue in asphalt mixes may be performed in a dry or slurry form. Slurry addition is done in advance of pugmill mixing, but requires added time and effort as compared to the dry mixing technique. Dry addition of lime to the pugmill results in appreciable amounts of dust generated.

Table 8-2

FIELD TEST INSTALLATIONS FOR PRODUCTS CONTAINING INCINERATOR RESIDUE

Location	Description	Year Constructed	Performance Evaluation
Bituminous Base Course Houston, Texas	1-1/2 inch conventional wearing surface on 6-inch base	1974	Good
Washington, D.C.	1-1/2 inch conventional wearing surface on 4-1/2-inch base and 6-inch conventional ground subbase	1977	Evaluation incomplete
Baltimore, Maryland	Unknown	1972	Good
Wearing Surface Philadelphia, Pennsylvania	108 feet, 1-1/4 to 1-1/2 inches thick	1975	Good
Harrisburg, Pennsylvania (fused aggregate)	250 feet, 1-1/2 inches thick	1975	Poor 1/
Lima, Pennsylvania	60 feet, 1-1/2 inches thick	1975	Fair 2/
Harrisburg, Pennsylvania (fused aggregate)	180 feet, 1-1/2 inches thick	1976	Excellent
Stabilized Base and Subbase 3/ Chicago, Illinois	Parking lot	1976	Good
St. Charles, Illinois	Parking lot	1974	Good
Stickney, Illinois	Roadway	1963	Poor 4/
Northbrook, Illinois	Parking lot	1962	Good

1/ Poor installation was probable cause.
2/ Asphalt stripped from glass particles.
3/ Twelve field tests have reportedly been made. Only four were reported in this study.
4/ Pulling and shrinkage of base material over time.

It is noted that blending of a natural aggregate with the incinerator residue in mixes is necessary to economize on the use of asphalt while at the same time increasing coatability of the mix. Control of the quantities of the components to be blended in the mixtures is of importance. The feeder control for blending of residue in residue/aggregate mixes is sometimes not easily controlled, due to the clogging and clotting capacity of the residue. This was evidenced in the Washington, D.C. section, as the designed residue to aggregate ratio in the mixture was not achieved for the first truckload batches. This situation was corrected at the beginning of placement operations, but not until after some of the mis-proportioned material had been placed in the field.

Stabilized Base and Sub-base. A disadvantage of using incinerator residue in base and sub-base applications is that the material requires a time period of approximately 3 days before placement of the wearing surface may be performed. This is required to eliminate potential damage to the wearing surface by hydrogen gas pressures that will develop in incompletely cured incinerator residue mixes. However, residue material compacts well in the field, although a determination of optimum moisture for compaction is difficult due to the high absorption by the material.

Another possible disadvantage of incinerator residue/lime material is that it does not appear to perform well under laboratory freeze-thaw testing, although high 180-day compressive strengths of +700 pounds per square inch and good California Bearing Ratio values have been attained for certain projects (i.e., Northbrook, Illinois).

It should be noted that only residue from rotary kiln incinerators have been used for this product. Also, variations in the type and quality of the lime in residue mixtures will slightly affect the strength of the mixtures.

In Wearing Surfaces. Wearing surface mixtures which contain incinerator residue may be batched directly at the asphalt plant as conventional mixes are, although more dust at the mixing plant may be created during the mixing and drying operations than occurs from the mixing of conventional materials. The fused residue mixtures can perform as well as conventional aggregate mixtures. When unfused residue is used, glass particle stripping must be controlled, and residue should be limited to 50 percent of the total aggregate, while fused residue can be used as total aggregate replacement. There appears to be an advantage for using residue/aggregate mixtures instead of conventional aggregate mixtures with respect to skid resistance. To measure the safety performance of incinerator residue in wearing surfaces, skid resistance tests were made on the control and experimental pavement sections. Two different types of skid resistance tests were used in evaluating the pavements. The two tests used were the BPN and SN40.*

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* A BPN (British Pendulum Number) of 55 correlates with a skid number (SN) of 40, as obtained from skid trailer measurements. A skid number of 40 is generally considered a minimum acceptable value for skid resistance of bituminous pavements in Pennsylvania.

To evaluate the Harrisburg fused aggregate section of pavement, the SN40 test was used. This test is standard ASTM Test E274. The test procedure involves using a specially equipped vehicle which can measure the tractive force of a test tire (horizontally applied force) as compared to a vertical load on the test wheel. The results of skid resistance tests performed on the Harrisburg fused aggregate test section are summarized in Table 8-3.

Table 8-3

SKID TEST DATA (SN40)

	Incinerator Residue	Control Section [1/]	
		Passing Lane	Traffic Lane
October 1976	52	40	44
April 1977	53	41	39
June 1977	50	-	-
October 1977	51	33	33
October 1978	46	36	33
September 1979	49	38	35

[1/] Adjacent section (Station 302+50) is an experimental blend of gravel and limestone aggregates.

Note: Skid number is average of three separate passes.

According to traffic count information provided by the Pennsylvania Department of Transportation, average daily traffic volumes for the fused aggregate test section in Harrisburg, varied from 640 to 4,917 vehicles per day. (This large variation was caused by temporary detours on nearby streets.)

To evaluate the Philadelphia section of pavement (which was a 50 percent blend of unfused residue with aggregate), the BPN test was used. The British Pendulum Number (BPN) test is standard ASTM Test E303. This test procedure involves measurement of forces on a dynamic pendulum impact device. This test was used due to the inaccessibility of the pavement to the SN40 test vehicle with respect to safety. The results of the skid resistance tests performed on the Philadelphia section are summarized in Table 8-4.

The test results from these two experimental sections indicate that the wearing surfaces with incinerator residue show slightly better skid resistance characteristics than their adjacent control pavement sections. This may be due to differential wearing of the particles of residue and aggregate. The BPN test results of the Harrisburg (Wayne Street) section also showed better skid resistance of the incinerator residue pavement as compared to the control pavement section.

Table 8-4

SUMMARY OF SKID RESISTANCE VALUES
PHILADELPHIA TEST SECTION

Date	Mix Type	Average BPN Value
March 1976	Control	87.0
March 1976	Residue	88.3
September 1976	Residue	87.7
September 1976	Control	84.7
November 1976	Residue	92.5
November 1976	Control	86.0

Bituminous Base Mixes. A disadvantage of using incinerator residue in bituminous mixes is that additional asphalt is required in the mix, beyond that required in conventional aggregate mixes.

Incineration facilities sometimes recycle the stack ashes from their burning operations back through the furnace to complete burnout. This results in the production of a more powdery or finely sized residue. If placed in a bituminous mix, this finely sized residue would require a greater amount of asphalt than a coarser sized residue.

An advantage of using incinerator residue in bituminous mixes as opposed to lime stabilized mixes is that the asphalt tends to bind or encapsulate the residue particles.

A careful distinction needs to be made between fused and unfused residue. Unfused residue is minimally processed and is the material generally used. Only one field test (Harrisburg wearing surface) is known to have been completed with fused residue. Although fused residue material is a high quality aggregate, the current high costs of processing residue to produce fused residue results in an uneconomical product.

SPECIFICATIONS

Because of the relatively low usage rate of use of incinerator residue in highway construction products, no guide specifications exist, and no states routinely use this material. In the very few cases where incinerator residue has been used in roadways, supplemental specifications have been developed. In these cases, laboratory tests have been conducted to determine mix designs, and these tests have formed the basis for the supplemental specifications. At this time, there are no known plans for a guide specification by FHWA, AASHTO, or ASTM.

COSTS

At this time, a detailed analysis of the economics of incinerator residue in construction applications (residue vs. virgin aggregate) does not provide the means to realistically judge the most economic alternative. The reason for this is that incinerator residue is not being routinely used in the aggregate market. There has only been a limited number of field applications to date, so exact cost comparison figures for in-place materials using incinerator residue have not been ascertained. In addition, indirect and undetermined costs involved with the use of incinerator residue on a large scale basis may be significant. This includes provisions for control of degree of burnout, provisions for monitoring of residue to be used including leachate testing, equipment and maintenance costs, transportation costs, and mixing and preparation costs. Long range effects on machinery that handle and process residue for construction applications have not been observed, as the machinery used in the past has not been operated for sustained periods of time. Detrimental long range effects may relate to unanticipated costs in the following areas: additional cleaning, part replacement from excessive wear, or even modification of equipment.

In a recent study performed for FHWA (Reference 8-5), the economic feasibility of using incinerator residue as an aggregate replacement in highway construction was assessed by using engineering estimating techniques. The results of that study show that if a credit for avoidance of landfilling is used, that unfused incinerator residue is an economic alternative in some cases. Important variables including the availability of acceptable quality residue and costs to transport the residue to the sites are needed. The important factor is the relation of the construction site to the virgin aggregate source and to the site of residue generation. Basically, the economics of transport restrict the use of incinerator residue to the regions of a metropolitan area most remote from the virgin aggregate sources. However, in any event, it is unlikely that incinerator residue could be used at distances in excess of 40 miles from the incinerator, and in most cases the construction site would have to be a distance of 20 miles or less. A summary of the study findings is in Table 8-5.

Table 8-5

PERCENT OF SELECTED SMSA [1] AREAS WHERE INCINERATOR RESIDUE IS CHEAPER THAN QUARRIED MATERIAL

	% of SMSA Where Unfused Residue Economical	
SMSA	Sub-base	Bituminous Mix
Chicago, Illinois	80	71
Miami, Florida	<1	0
Harrisburg, Pennsylvania	11	0
Washington, D.C. - Virginia - Maryland	65	45
New York, New York - New Jersey	100	47

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[1] Standard Metropolitan Statistical Area.

Source: Reference 5-5.

The same study also concludes that use of fused residue is not economically feasible at this time.

ENERY AND ENVIRONMENTAL ANALYSIS

An assessment of the impact of using incinerator residue on energy supplies and on the environment was made, and the detailed results can be found in Appendix D. The assessment summarized here is a comparison of three options for stabilized base courses. Two options considered utilization of incinerator residue. They are asphalt concrete with one-half of the aggregate replaced by incinerator residue (IR); and a pozzolanic stabilized base using lime kiln dust in conjunction with IR. The conventional material used for comparison is asphalt concrete. The examples chosen are more fully disclosed in Figure 8-2 Table 8-6 is a summary of the results.

Table 8-6

ENERGY AND ENVIRONMENTAL IMPACTS OF USING INCINERATOR RESIDUE IN STABILIZED BASE COURSE ALTERNATIVES

(One mile of 2-lane road)

	Asphalt Concrete	Asphalt-Incinerator Residue-Aggregate	Lime Kiln Dust-Incinerator Residue
Energy (10^9 Btu)	6.1	11	1.7
Air Pollution (10^3 lb)	35	28	10-22
Water Pollution (10^3 lb)	2.4	4.1	0.7
Processing Solid Waste (10^3 lb)	4.4	4.5	3.1
Materials Diverted from Waste (10^3 lb)	0	2,600	6,100

Source: Franklin Associates, Ltd.

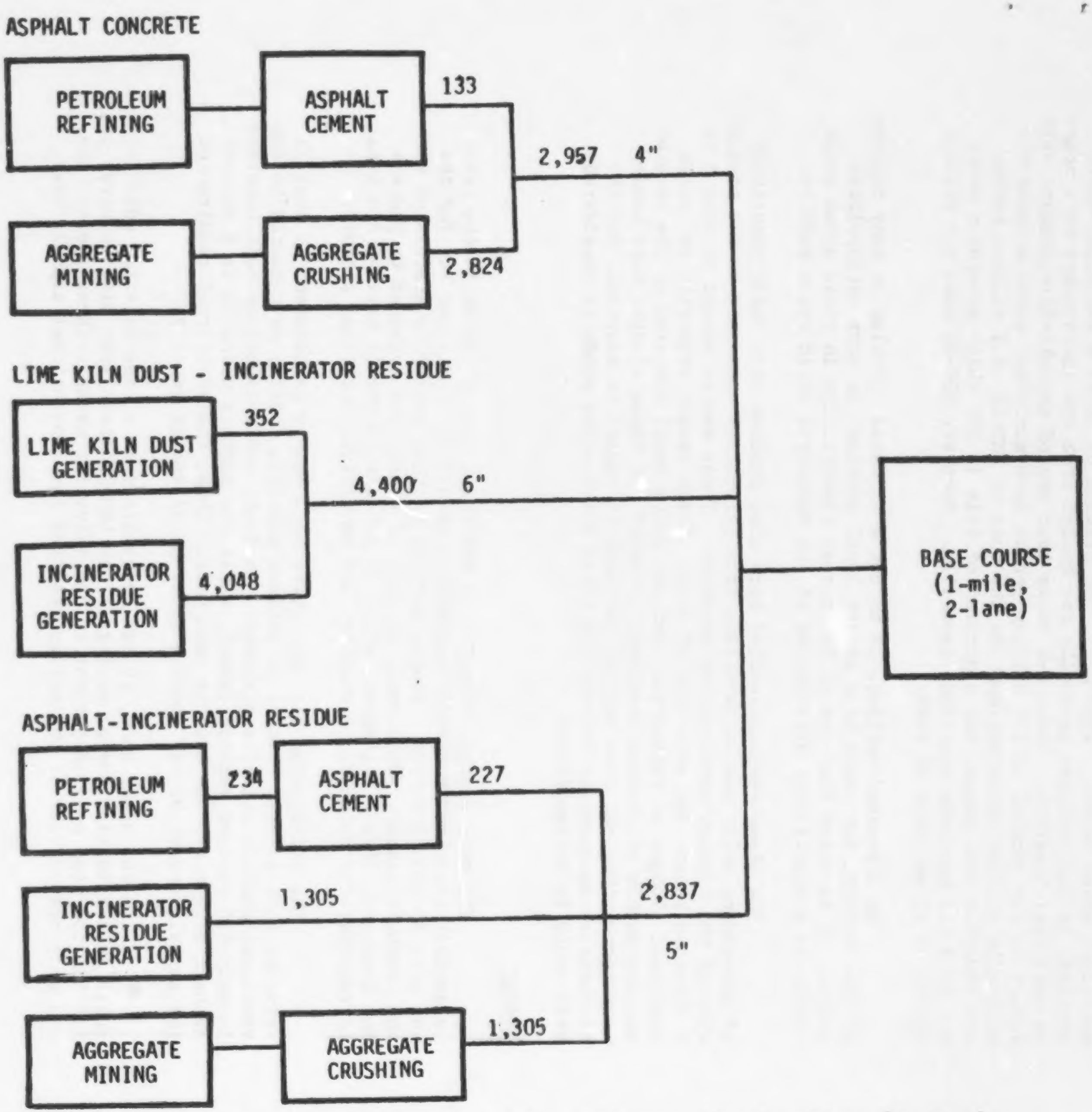
ASPHALT CONCRETE
PETROLEUM REFINING
ASPHALT CEMENT
133
AGGREGATE MINING
AGGREGATE CRUSHING
2,824
2,957
4"
LIME KILN DUST - INCINERATOR RESIDUE
LIME KILN DUST GENERATION
352
INCINERATOR RESIDUE GENERATION
4,048
4,400
6"
BASE COURSE (1-mile, 2-lane)
ASPHALT-INCINERATOR RESIDUE
PETROLEUM REFINING
234
ASPHALT CEMENT
227
INCINERATOR RESIDUE GENERATION
1,305
2,837
5"
AGGREGATE MINING
AGGREGATE CRUSHING
1,305

Figure 8-2. Materials flow for incinerator residue and conventional options (in tons).

Solid Waste

One of the goals of RCRA is alleviation of the disposal problem of municipal solid wastes. Typically, the problem of IR is a municipal waste problem, as the residues generally are hauled from the incinerator to a nearby municipal landfill. Table 8-6 shows that use of asphalt-IR-aggregate will result in the removal of 2.6 million pounds from municipal waste streams for each mile of road construction. In the case of LKD-IR, 6.1 million pounds are diverted from waste, but a portion of this is LKD which generally would not find its way into municipal landfills. However, LDK-IR uses 5.6 million pounds of IR per mile of road.

As discussed earlier, IR is not a critical problem in many regions of the country, but could be a severe local problem in many metropolitan areas. It is clear that use of IR in road construction in those areas could result in a significant alleviation of the municipal solid waste problem.

The three options studied here also produce very small quantities of processing solid wastes resulting from activities necessary to the production of the highway construction products. These wastes amount to only 3 to 4 thousand pounds for each mile of road. These result primarily as waste treatment sludges at refineries, but are quite small compared to the several million pounds of product involved. However, if these sludges have toxic components, they may pose special problems in regard to disposal, but the differences in quantity between the three alternative products considered here would be insignificant.

Energy

The most energy-intensive of the three options shown in the table is asphalt-incinerator residue-aggregate, requiring 11 million Btu for the one mile of two-lane road. Eighty percent of this energy is associated with the asphalt cement. Only small amounts of energy are required to process and transport IR and aggregate, while 13 percent of the 11 billion Btu total is required for batching, spreading, and compacting the final product.

The explanation for this quite high energy requirement is that IR requires more asphalt cement to achieve particle coating as compared to conventional asphalt concrete mixtures. In fact, conventional asphalt concrete is only 4.5 percent asphalt cement, while the mixture using IR is 8 percent asphalt cement for the example used here. Thus, the additional requirement for asphalt cement brings about a substantial energy penalty.

On the other hand, IR can be utilized in a base material which results in substantial energy savings. The LKD-IR stabilized base requires only 1.7 billion Btu, only 15 percent of the value for asphalt-IR-aggregate base, and only one-quarter of the energy required for conventional asphalt base.

An important point here is that the energy content of the asphalt cement itself is included. Franklin Associates has determined by contacting petroleum refineries that asphalt cement is diluted and sold as a fuel oil if it is not sold as asphalt cement. Thus, its use in highway construction results in the removal of a fuel from the world's finite fossil energy inventory, just as if it had been burned. This is an important assumption. Reference to Appendix D shows that if the fuel content of the asphalt is subtracted out, then the energy for the conventional asphalt concrete option is 4.0×10^9 Btu, while the energy for the asphalt-IR-aggregate option is 8.4×10^9 Btu. Thus, the relative ranking of these options is still the same, but the energy factor for the two options requiring asphalt cement is substantially reduced.

Air Pollution

The predominant air pollution problem for these products is particulates, primarily resulting from dust generated during aggregate mining and crushing, and to a lesser extent from handling IR and kiln dusts. Table 8-6 shows that less air pollution is generated by the kiln dust-IR system, primarily because no conventional aggregate is used. However, copius quantities of dust can be produced in the handling of either IR or kiln dusts. If these materials are handled properly (in closed equipment for loading, unloading, storage, and transport) and are applied using proper wetting, then the results in Table 8-6 are valid. However, the results could favor any of the products assessed if inadequate dust control procedures are used.

Water Pollution

Water pollution associated with the products discussed here is minor. The only water pollution associated with these systems results from production and refining of fuels and asphalt cement, but the amounts involved are relatively small.

Another primary environmental consideration related to incinerator residue materials in construction applications is leachate. Leachate production and composition are related to solubility, permeability, and chemical composition of the residue.

Generally, water penetration through incinerator residue is relatively low, as the permeability of residue may be considered equivalent to that of a silty sand or fine sand. The toxic substances contained in residue materials can be determined by chemical analysis of the material itself, and are found to be trace metals including arsenic, cadmium, copper, and lead. With respect to these toxic substances, the Environmental Protection Agency has established a guideline for Safe Drinking Water Standards. A concern exists if the extract from the material (obtained by a testing means such as the EP toxicity test method) has a concentration of any constituent greater than one hundred times the established water standard.

It was reported in leachate testing performed during 1980 by the Pennsylvania Department of Transportation, as well as by the Port Authority of New York and New Jersey, that concentrations of chemicals in excess of one hundred times the drinking water standard were measured on tested samples of incinerator residue. The samples tested by the Pennsylvania Department of Transportation came from an incinerator located in Central Pennsylvania (Reference 5-8). The samples tested by the Port Authority of New York and New Jersey came from two resource recovery plants located in the northeastern region of the United States (Reference 5-9). The Port Authority report indicated a lead level greater than three hundred times the drinking water standard. Thus, the use of this material, "as is," in a construction fill application would be restricted. This material would have to be disposed of by acceptable solid waste management techniques.

However, in the bituminous base application, the leachate from the residue may not be hazardous due to the encapsulating effect of the asphalt. Also, when stablized by LKD, the permeability may be reduced so that the leachate will be rendered non-hazardous.

As a part of this research project, one sample of a bituminous base containing IR was obtained from an existing road. This sample was subjected to leachate extraction procedures, with the leachate being subsequently evaluated by standard laboratory procedures. The procedures used were in accordance with EPA recommendations.

Included in Appendix E, Volume 2, is a description of the method used in the leaching tests, the Federal Register notice describing the "EP Toxicity Test," and a summary of the results.

Although a test on a single sample was not of sufficient magnitude to extrapolate the results to all highway construction products containing incinerator residue, the test did not indicate that there is an environmental hazard. As far as is known, there are no known leachate extraction test results from field highway construction samples that do indicate any significant toxic leachate associated with this kind of use where the IR is encapsulated.

Summary

It is clear that the requirement of asphalt cement for asphalt-IR-aggregate base courses renders that option by far the most energy intensive option. This option may or may not result in more air pollution than conventional asphalt concrete, depending on the care in handling the dust problem associated with IR. Because of the significant use of asphalt cement, the asphalt-IR-aggregate option also results in more water pollution.

These somewhat negative energy and environmental conclusions discussed here are balanced to some degree with the fact that use of IR may result in a significant alleviation of municipal solid waste steams. In addition, IR may generate leachate under some conditions that could be classified as hazardous. The stabilization and/or encapsulation of IR with asphalt cement or LKD may render the leachate non-hazardous.

The analysis of pozzolanic stabilized base (LKD-IR) results in less ambiguous conslusions. It results in less energy and environmental impact than the other two options in every category, so that its use is quite desirable from that point of view.

GUIDELINE OPTIONS

Introduction

There is a broad range of guideline options available to EPA. The two extreme options would theoretically be no guidelines at all, or mandatory guidelines that would require fixed minimum amounts of recovered materials. These two theoretical extremes are discussed in Chapter 3. Between these two extremes are a number of more reasonable options. Several reasonable options are presented and analyzed in this section.

In the material which follows, a brief summary of the conclusions reached in this chapter is presented, followed by an analysis of guideline options. Those options are: (1) dual bids; (2) dual bids applicable to selected locations; (3) increase and improve educational activities; (4) use of grants, bonuses, increase funding for research and testing, or other financial incentives; and (5) phase in, or delay of guideline implementation. Advantages and disadvantages of each option are presented, but no option is singled out for recommendation by the authors. These options apply only to unfused residue, as fused residue does not appear to be an economical alternative.

Dual Bids

One guideline option available to EPA is to require that IR be specified as one possible material. For example, a procuring agency might specify that either a conventional asphalt concrete base of a certain thickness, or an asphalt concrete-IR-aggregate base of a certain thickness, could be proposed by a bidder (but with the IR-aggregate blend being no more than 50 percent IR, and the IR must meet the same gradation requirements as the aggregate).

This dual bid would take one of several forms depending on state laws. In some cases, the appropriate form would be as an alternate bid. When this mechanism is used, the bid document instructs the bidder that their bid must include either IR-aggregate blends or conventional aggregates. Thus, the choice of material is fixed at the time of contract award, and the winning contractor uses the material that he chose when preparing this bid.

In some states the mechanism used in an optional approach. In that form, the contract is awarded before the material choice is made. That is, the job is bid at a certain price, and the contractor agrees to select one of the optional materials at a later time. Then, when construction begins, the contractor exercises his option to decide which material will be used, which usually is the material which results in the least cost to him at that time. However, some provision would need to be made because no states have IR specifications for routine use. In some states where tests have already been made and evaluated, this may only require one or two years. However, in states where tests are not completed it may require as much as five years.

Advantages. The advantage of the dual approach is that recovered material used is encouraged. If a contractor wants to use IR and feels that he can be low bidder by so doing, this opportunity is available to him. The dual bid approach is a strong approach in that it requires procuring agencies not experienced in the use of IR to become knowledgeable about that material and to specify which applications are most suitable. It insures that competition will be maximized by allowing contractors to bid conventional aggregates or IR. Thus, no potential contractors are excluded from the competion because of a material requirement. This procedure also insures that the material will be readily available, because contractors will not bid a material for which this uncertainty exists. Finally, the dual bid approach insures that products are purchased at the least cost to the procuring agency because of the competitive bid situation.

Disadvantages. Dual bids cause an inconvenience in locations where IR will not win bids. In most locations, IR is not available locally and cannot be transported economically. Thus, any rule requiring dual bids would result in unnecessary work for the procuring agency. Also, in many states, dual bids result in the necessity of preparing separate designs for each material. Although in some states this is a minor problem, in others it is considered a major problem. In any event, if IR aggregate blends never win bids, any extra effort to prepare a dual bid would be considered as wasted effort by the procuring agency.

Also, because no states presently have a specification for routine use of IR, this guideline option would have to have a delayed implementation. However, some states would be able to prepare specifications in a relatively short time because of previous experience, and most states could adopt a temporary or supplemental specification. Thus, one or to years should be sufficient.

Another problem with dual bids is that they will not be successful in stimulating use of IR where procuring agencies do not believe it is an acceptable material. The dual bid procedure can be easily circumvented by writing some provision into the specification that will insure that IR would never be cost competitive. Perhaps the easiest way to do this would be to assign materials using IR a low structural number, so that an unnecessarily thick layer would be required. This could insure that IR would never win a competitive bid. These acts by a procuring agency may be based on a convert attempt to avoid use of a material, are difficult to identify and correct, because experimental data may be cited which support their position. The extremely wide variations in composition and quality of construction materials available in a given place, along with extreme variations in climate, soils, and other environmental conditions, make independent judgment of design specifications difficult.

Dual Bids Applicable to Selected Locations

Incinerator residue is readily available only in certain ares. IR is presently found only in or quite near large cities. In fact, all the incinerators identified are in standard metropolitan statistical areas (SMSAs). Also, as pointed out previously, it is likely that IR use will be economical if construction sites are located closer than 20 to 40 miles from an incinerator. Thus, it would appear that IR use will generally occur only within SMSAs. A guideline could specify that dual bids need only be required for projects within SMSAs, Where an incinerator of selected minimum size exists. Alternatively, the guidelines could specify that dual bids are required if a construction site is within a circular area of some given radius (perhaps 40 miles) centered on an incinerator.

Advantages. A primary advantage of this guideline is that it does not cause a paperwork burden in areas where a problem is not perceived, and the lack of availability of IR would preclude its widespread use.

In addition, for the areas specified, IR would be available in the region of interest. If whole states were included, most regions of the state would be remote from the incinerator and would never use IR. Thus, the dual bids procedure would work most efficiently by excluding the vast areas of the country where IR use is not economically feasible.

Disadvantages. A selective guideline procedure may not maximize the use of IR. In some areas conventional aggregates are in short supply, and IR may be imported from more than 40 miles and be economically used. These areas would be excluded by the guidelines. However, it is assumed that this would be true in only a small number of locations.

Increase and Improve Educational Activities

A guideline requiring dual bids places requirements on direct Federal procurements, and to a much greater extent places a requirement on state and local highway construction procuring agencies. An alternate to this approach is to put more of the responsibility on the Federal government. One way of doing this is to require that the Federal Highway Administration (FHWA) increase and improve their educational activities. It is clear that at the headquarter level in Washington, D.C., FHWA has acted to promote and encourage the use of IR by preparing and disseminating educational materials to the FHWA regional offices. However, from the interviews with the states, it is clear that most district level FHWA engineers have not promoted the use of IR. Thus, the focus of this activity would be to insure that FHWA district engineers in every state are well trained in the use and new developments of IR materials. In turn, they should make state departments of transportation officials aware of the importance of use of IR as a national policy and of the importance for each state to seriously study the potential advantages of use of IR within the state. Dissemination of information and conducting training sessions for state district engineers should be encouraged. Perhaps key states, such as the seven states mentioned previously, could be targeted for this activity initially.

FHWA has recently increased activity in this area. Thus, EPA should remain current on the present status before implementing guidelines.

Advantages. An advantage of this guideline is that it does not force the use of IR or even of dual designs and therefore will insure that its use can be carefully evaluated by each procuring agency. It would be a wise approach from the point of being less "heavy handed" with regard to the states by not placing requirements for dual bids on them. However, it should increase the awareness of IR and would likely result in more use.

Disadvantages. A disadvantage of this guideline option is that it may result in less immediate use of IR than a dual bid guideline. Also, it will require expenditures on the part of FHWA to provide a staff to implement this activity. Because of a generally tight budget situation, this may cause some difficulty for that agency.

Another disadvantage is that in some cases district engineers will ignore these guidelines to the extent possible; in other cases, they may be overzealous and place undue pressure on states to use recovered materials to the extent that they would be used in inappropriate or uneconomical applications. Either of these types of action would be contrary to the intent of the guidelines.

Increase Funding for Research and Testing

The use of IR does not involve complex technical issues because it is basically conventional and serves as an aggregate replacement. This basic nature is understood and its applications can be readily identified by those knowledgeable about the material. However, sufficient tests have not been performed by many states. Thus, FHWA could make money available to states for additional research and testing of IR.

Advantages. An advantage of this guideline is that it would decrease the time until IR could be included in state specifications. This would increase the user's ability to incorporate IR in road construction and to increase the reliability of installation. This would enhance its salability and lead to wider use.

Disadvantages. The main disadvantage would be that FHWA would likely have to divert research funds from other projects which they have identified as being more important. Thus, a basic policy decision would need to be made that it is more important for FHWA to conduct research alleviating the solid waste problem than to fund additional research for IR solely on its merit as a highway construction material. FHWA has already made its judgment with regard to the merits of IR based on research that has already been done, and this guideline would essentially require them to alter those decisions in favor of funding more effort on IR.

An alternative may be additional funding by Congress for these activities. If use of recovered materials is deemed to be in the national interest, this would be justification for increasing the FHWA budget in order to fund these activities.

Another disadvantage of this guideline is that the payoff might be low. The problems with IR are already well understood and solutions are known. Thus, additional funding for research in this area may in many ways repeat previous work.

Use of Grants, Bonuses, or Other Financial Incentives

A way to encourage procuring agencies to use more IR is to use financial incentives. This could take many forms. It could include block grants to states to use IR, or to experiment with its use. Another option would be to grant a bonus on projects using IR. For example, if the normal federal share of a particular road were 70 percent, a state could be granted a bonus to use IR on the roadway and receive a greater Federal share, say another 5 percent added to the 70 percent to make 75 percent for the portion of the project where IR was used.

Perhaps this program could be implemented as an extension of current FHWA demonstration programs, where financial incentives are offered to states for first time installation of demonstration or test sections.

Advantages. This would be one of the most rapid ways in which to increase the use of IR. A serious problem facing virtually all highway construction entities is a shortage of funds. Providing money for road-building and maintenance in any form would be met with a more positive response than any other option.

Disadvantages. The most serious disadvantage to this guideline would be the locating of funds. FHWA administers the Federal funding of highway construction projects, and they are suffering a severe errosion of funds which can be used for highway construction. Therefore, a basic policy decision would have to be made that money could be diverted from other uses for the purpose of funding these guideline options. However, as discussed previously, an alternative would be for Congress to increase funding levels because use of recovered materials is deemed to be in the national interest.

Another disadvantage is that the economics of IR already stimulate its use in some locations. Some projects would receive additional funding that would be unnecessary because IR would be used anyway.

Another potential problem with this guideline option is that it is possible that legal barriers might exist which would not permit certain kinds of financial incentives. These would have to be carefully investigated.

Delay Guideline Implementation

A final guideline option is to delay implementation of a specific guideline option for a specified number of years. For example, EPA could publish their intent to implement a dual bid guideline in 5 or more years.

Advantages. In 5 years, the amount of incinerator residue available will have increased substantially, and probably more installations will have been placed thereby allowing more complete evaluation. Thus, the picture on how and where IR should be used would be clearer. In addition, a formal notice by EPA of the intent to implement a guideline for IR would give procuring agencies time to develop specifications and to plan for the best use of the material and determine how best to comply with a guideline.

Disadvantages. The primary disadvante of this option is that it would delay any definitive action by EPA and would therefore delay any possible benefits of a guideline.

Chapter 8

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